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DESIGN/PRODUCTION INTEGRATION  
HUMAN RESOURCE INNOVATION  
MARINE INDUSTRY STANDARDS  
WELDING  
INDUSTRIAL ENGINEERING  
EDUCATION AND TRAINING

# **THE NATIONAL SHIPBUILDING RESEARCH PROGRAM**

## **1995 Ship Production Symposium: Commercial Competitiveness for Small and Large North American Shipyards**

U.S. DEPARTMENT OF THE NAVY  
CARDEROCK DIVISION,  
NAVAL SURFACE WARFARE CENTER

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# 1995 SHIP PRODUCTION SYMPOSIUM

## Commercial Competitiveness for Small and Large North American Shipyards

Seattle, Washington  
The Westin Hotel  
January 25-27, 1995



**Sponsored by the Ship Production Committee  
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## **TABLE OF CONTENTS**

<b>Technology Survey of U.S. Shipyards - 1994 .....</b>	<b>1-1</b>
Richard Lee Storch (M), University of Washington, U.S.A., John Clark (V), A & P Appledore International, Ltd., U.K., and Thomas Lamb (FL), Textron Marine & Land Systems, U.S.A.	
<b>Technology Development: A European Experience .....</b>	<b>2-1</b>
John Craggs (M) and Malcolm Bell (V), First Marine International Limited, U.K., Simon Quarrell (V), KPMG Peat Marwick, Europe, and Francisco Laranjeira (V), Estaleiros Navais de Viana do Castelo, Portugal	
<b>Economics and Management of American Shipbuilding and the Potential for Commercial Competitiveness .....</b>	<b>3-1</b>
Ernst G. Frankel (LM), Massachusetts Institute of Technology, U.S.A.	
<b>Tee-Beam Manufacturing Analysis: Producibility of Panel Stiffening Elements .....</b>	<b>4-1</b>
Paul A. Blomquist (V), Bath Iron Works Corporation, U.S.A.	
<b>Producibility of Double Hull Tankers .....</b>	<b>5-1</b>
John C. Daidola (M), John Parente (AM) and William H. Robinson (M), M. Rosenblatt & Son, Inc., U.S.A.	
<b>Build Strategy Development .....</b>	<b>6-1</b>
John Clark (V), A & P Appledore International Ltd., U.K., and Thomas Lamb (FL), Textron Marine & Land Systems, U.S.A.	
<b>Generic Build Strategy - A Preliminary Design Experience .....</b>	<b>NOT AVAILABLE FOR PUBLICATION</b>
Perry Singh, Advance Marine Enterprises, Inc., U.S.A., Todd Cary, Naval Sea Systems Command, U.S.A., and James R. Wilkins, Jr., Wilkins Enterprise, Inc., U.S.A.	
<b>Development of Integrated Shipyard Pipe Production Facility .....</b>	<b>8-1</b>
Emlyn L. Jones (M), Jesse Engineering Co., U.S.A., and Terry Watne (V), Advanced Control Technology, U.S.A.	
<b>Standard Outfit Package Units in the LPD 17 Ship Design: A Production Impact Study .....</b>	<b>9-1</b>
Walter L. Christensen (M), NAVSEA Shipbuilding Support Office, U.S.A., and Philip C. Koenig (M), Shipbuilding Technologies Office, David Taylor Model Basin, U.S.A.	
<b>Robot Technology in the Shipyard Production Environment .....</b>	<b>10-1</b>
Svein I. Sagatun (V), and Karl Erik Kjelstad (V), TTS International AS, Norway	

Shipbuilding Robotics and Economics .....	11-1
Ronald C Reeve, Jr. (V) and Robert Rongo (V), CYBO Robots Inc., U.S.A.	
Naval Shipyard Base Realignment and Closure: The Environmental Remediation Effort .....	12-1
Rodney K. Pieper (V), Mare Island Naval Shipyard, U.S.A.	
3-D Computerized Measuring Systems for Increased Accuracy and Productivity in Shipbuilding and Repair .....	13-1
Michael D. Holmes (V), The IMTEC Group, Ltd., U.S.A.	
Spanish Shipbuilding: Restructuring Process and Technological Updating From 1984 to 1994 .....	14-1
Jose Luis Cerezo (V) and Sanchez-jauregui (V). The Shipbuilding Sector Agency (Department of Industry) Spain	
The Netherlands' Shipbuilding Industry: Own solutions to competitiveness .....	15-1
Michael Goldan (V), BOS Foundation for Shipyard and Industry Development The Netherlands	
Automated Blasting and Recovery of Coatings Removed From Ship Hulls .....	16-1
Gary K. Sweet (M), Sandroid Systems, Inc., U.S.A.	
Navy High-Pressure Waterjet Closed-Loop Paint Stripping System.....	17-1
John Williams (V), Naval Surface Warfare Center, Carderock Division, U.S.A., and Robert M. Rice (V), United Technologies, Pratt & Whitney Waterjet Systems, Inc. U.S.A.	
Analysis of Competitiveness in Commercial Shipbuilding .....	18-1
Sjoerd Hengst (M), Delft University of Technology, The Netherlands, and J.D.M. Koppies (V), Van Holst & Koppies, The Netherlands	
Experiences of Introducing ISO 9000 and Total Quality Management in U.K. Shipbuilding and Ship Repairing.....	19-1
Geoff French (V) and Derek Eltringham (V), Association of Independent Management and Maritime Services, U.K.	
The Product Model as a Central Information Source in a Shipbuilding Environment .....	20-1
Kaj Johansson (V), Kockums Computer Systems AB, Sweden	
The Influence of Integrated CAD/CAM Systems on Engineering for Production Methodologies in Shipbuilding .....	21-1
Jonathan M. Ross (M), Proteus Engineering, U.S.A., and Luis Garcia (V), SENERMAR Spain	

Past and Present Concepts of Learning: Implications for U.S. Shipbuilders .....22-1  
Mark H. Spicknall (AM), University of Michigan Transportation Research Institute, U.S.A.

Concurrent Engineering Application and Implementation for U.S. Shipbuilding .....23-1  
James G. Bennett (AM), Bath Iron Works Corporation, U.S.A., and Thomas Lamb (FL), Textron Marine & Land systems, U.S.A.

**Absenteeism Management**.....24-1  
Blaine Lewis (V), Saint John Shipbuilding Limited, Canada

Implementing Interactive Multimedia Training .....25-1  
Ralph E. Matlack (AM) and Edward Matlack (V), M/Path, U.S.A.

Marketing Strategy for Merchant Shipbuilders .....26-1  
Paul W. Stott (V), A& P Appledore International, U.K.

Increasing U.S. Shipbuilding Profitability and Competitiveness .....27-1  
Frank H. Rack (M), Managing Change, Inc., U.S.A.

A Production Control System Based on Earned Value Concepts .....28-1  
Ram6n de la Fuente (V) and Ernesto Manzanares (V), Astilleros E-spanoles, S.A., Spain

A Comparative Study of U.S. and Foreign Naval Acquisition, Design and Construction  
Policy and Practices.....29-1  
Patrick D. Cahill (AM) and Howard M. Bunch (LFL), University of Michigan Department of Naval Architecture and Marine Engineering, U.S.A.



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## Technology Survey of U.S. Shipyards - 1994

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### ABSTRACT

This paper reports on the results of a study of the international competitiveness of the U.S. shipbuilding industry. It describes the results of a detailed technology survey of 5 U.S. and 5 overseas shipyards. It then discusses the relative levels of technology application by the U.S. and overseas industries. A detailed competitive analysis is then presented. Finally, specific areas for improvement needed by the U.S. industry are recommended.

### INTRODUCTION

Over the past decade, large U.S. shipyards involved in new construction have concentrated on the building of vessels for the U.S. government, primarily combatants and auxiliaries for the U.S. Navy. The few merchant ships that have been built were for the Jones Act trade, in which foreign shipbuilders were precluded from competing. This workload was sufficient to maintain the industry during the build up to the "600 ship Navy" in the late 1980's. Events after that have led to a dramatic downturn in shipbuilding for the U.S. Navy. As a result, U.S. shipyards must seek other customers in order to remain in business. Since the U.S. merchant ship fleet is relatively small, U.S. shipbuilders will be forced to compete for shipbuilding contracts for foreign ship operators. This puts the U.S. shipyards in direct competition with shipbuilders throughout the world.

As U.S. shipyards prepare to compete for merchant shipbuilding for export, it will be important for them to understand their worldwide competitive position. The broad objective of this work is to help provide that information. This report is the result of a study sponsored by the National Shipbuilding Research Program entitled "Requirements and Assessments for Global Shipbuilding Competitiveness" (Storch, 1994). The study was the result of a combination of three individual project

abstracts, two from Panel SP-4, Design/Production Integration and one from Panel SP-1, Facilities and Environmental Effects.

There were five objectives of this research. They were:

- 1 to determine the relative technology levels in use in shipyards in the U.S. and in leading shipyards overseas;
- 1 to determine the relative status of shipbuilding/ship repair facilities in U.S. and leading overseas shipyards;
- 1 to determine the facilities required by U.S. shipyards to compete against leading overseas shipyards and to evaluate the relative cost effectiveness of any required facility improvements;
- 1 to provide an indication of the competitive position of U.S. shipyards in relation to the leading overseas shipyards in terms of cost and time, and to determine how overseas shipyards are currently able to produce ships in a shorter time and for less cost than U.S. shipyards; and
- 1 to identify the major factors to be addressed and actions taken in order to allow U.S. shipyards to enter the international shipbuilding/ ship repair market on a competitive basis, relating to technology levels, operational practices (both internal and external to a shipyard), and facilities.

A key element of the research was a detailed survey of 10 shipyards. 5 in the U. S., 4 in Western Europe and 1 in Japan. These surveys were used, along with other sources, to obtain answers to the questions posed by the 5 objectives of the research listed above. The data associated with each individual shipyard survey will be kept confidential. us agreed to by the

study team and the shipyards involved. Thus the results are averages, used to determine trends and general levels, rather than relating to specific shipyards. The research team believes the cross section of shipyards surveyed provides a valid description of the current state of international and U.S. shipbuilding competitiveness. Although 5 U.S. yards were surveyed, this paper uses data from only the 4 large yards, in order to provide a better base for comparison.

## TECHNOLOGY SURVEY

The technology survey performed not only examines how up to date a shipyard's hardware and facilities are, but also the procedures used to operate them, the methods used to plan and control the work and the production of engineering information. The results of a survey are an important indicator of a shipyard's performance and capability and can be used to compare shipyards anywhere in the world.

For the purposes of a full technology survey the overall shipbuilding process is divided into 72 elements which cover the whole operation (A&P Appledore, undated). However, for this survey of U.S. shipyards the three elements relating to amenities (canteen, washrooms and other amenities) were not addressed. The remaining 69 elements are shown in Table I.

The measurement of the efficiency of each element, in terms of technology levels, provides a consistent method of comparing different shipyards. When more than one surveyor is used for the examination the results become more objective. Three surveyors were used for most of the shipyard visits for this project. In order to take account of their relative importance in the shipbuilding process, weightings are applied to each element and group of elements.

Five levels of technology have been identified. These correspond to the state of development of the most advanced shipyards at different times over the last 34 years. Those yards which are less advanced remain at the level of technology of an earlier period. The technology level is described for the whole yard, for the seven major areas of shipyard operation, and for the 69 individual elements. In each case, the yard under review is rated according to the description which most closely matches its situation. In this way a consistent assessment can be made, and the results of the review used to compare shipyards.

For the whole shipyard, the five levels of technology are described below:

Level 1 reflects shipyard practice of 1960. The shipyard has small cranes, several berths in use and very little mechanization. Outfitting is largely carried out on board ship after launch. Operating systems are basic and manual.

Level 2 is the technology employed in shipyards modernized during the late 1960's or the early 1970's. Fewer berths are in use, or possibly a building dock, larger cranes and some degree of mechanization. Computing is used for some of operating systems.

Level 3 is good shipbuilding practice of the late 1970's. It is represented by the new or fully redeveloped shipyards in the U.S., Europe or Japan. There are large cranes, some environmental protection and a single dock or level construction area. A large degree of mechanization and the use of computers is evident.

Level 4 refers to shipyards that have continued to advance their technology during the 1980's. Generally a single dock is used, with good environmental protection. Fully developed operating systems and extensive early outfitting are evident.

Level 5 represents state of the art shipbuilding technology in 1990. It is developed from level 4 by means of automation in areas where it can be used effectively, and by integration of the operating systems, for example by the effective use of CAD. It is characterized by efficient, computer aided material control and by effective quality assurance.

## COMPENSATED GROSS TONNAGE

Compensated Gross Tonnage (CGT) is used to provide a common yardstick to reflect the relative output of merchant shipbuilding activity in large aggregates such as "World", "Regions" or "Groups of many yards" (Bruce, 1992). The compensation of the measured Gross Tonnage is to take into account the influence of ship type, complexity and size on work content. For example, the work content of a passenger ship per Gross Ton is larger than that of a tanker or bulk carrier.

In 1984, the present system of calculating CGT was adopted by the Organization for Economic Cooperation and Development (OECD), the

Association of West European Shipbuilders (AWES) and the Shipbuilders' Association of Japan (SAJ). The coefficients are currently under review, particularly to accommodate double hulled tankers.

Because the system was intended to measure the relative output of large groups of shipyards, it has had to be modified slightly for application to small groups or individual shipyards. The coefficients for converting GT to CGT cover bands of sizes within the different ship types. Thus, each ship type is covered by a step function which can cause anomalies when ships have only slightly different deadweights and could have coefficients with significantly different values applied. To overcome this, and make the measure useful for performance comparisons of individual shipyards, the coefficients have been plotted for each ship type and values located at the mid point of the range of sizes to which they relate. Curves were then drawn through the points and these curves we used to determine the coefficient to apply.

The relative position of a shipyard gives guidance as to the improvement in cost or performance needed to become competitive. There is generally a reasonable correlation between the global performance of a shipyard and the performance of each part of the shipyard. Mismatches between global and local performance could indicate bottlenecks to productivity improvement. The necessary global performance assists target setting for local performance parameters.

The comparative measure used for assessing the individual shipyard's performance is its labor cost of producing a CGT. To compare with shipyards worldwide, the cost is converted to U.S. Dollars. The Cost/CGT is not based upon the total cost of building a ship, as materials are not included. The measure is, however, directly related to the efficiency and competitiveness of a shipyard, as the labor costs are those most under its control.

In order to derive the Cost/CGT the productivity of the shipyard's employees in terms of Employee Years to produce a CGT and the Cost of an Employee Year must be derived, i.e.:

$$\text{Cost/CGT} = \frac{\text{Cost/Employee Year}}{\text{x Employee Years/CGT}} \quad (1)$$

Another useful measure of a shipyard's productivity is the number of direct worker man-hours required to produce a CGT.

## REQUIRED INFORMATION

In order to evaluate competitiveness, a substantial amount of information has to be obtained for a shipyard. This information is described below.

### Ship Production

To assess recent productivity, details of the ships completed over the previous three years should be obtained. Three year's data is required as a minimum in order to average out the effects of ships in the process of being built at the beginning and the end of the period. The required information is ship type, deadweight and gross tonnages, and the applicable CGT coefficient. The initial information is obtained from the shipyard while the CGT Coefficient can be obtained from the CGT Coefficient plots mentioned earlier. CGT is obtained by multiplying the GT by the CGT Coefficient. In order to obtain the average annual output of the shipyard, the CGTs are summed and divided by the number of years of output represented.

### Shipyard Personnel

Productivity is measured by the effort, in terms of man-hours required to produce an amount of work (in this case CGT). Annual numbers are required for the following people who are employed in shipbuilding activities (i.e., excluding ship repair or any other industrial activity):

- . direct shipbuilding workers;
- . direct shipbuilding subcontractors;
- 1 indirect shipbuilding workers; and
- 1 indirect shipbuilding subcontractors.

The definition of direct and indirect workers, and subcontractors varies with country and with shipyards within countries so some adjustments to the supplied figures may be necessary. Occasionally the personnel may be subdivided into direct, indirect and administrative indirect. Whatever the subdivisions used the total number of employees involved in shipbuilding is given by the sum of the direct workers and the indirect workers (including the relevant subcontractors).

Ideally the above information should be obtained for each workshop and department within a shipyard as it may be useful in assessing the productivities of the various activities in the shipbuilding process for later, more detailed studies. It is however imperative

to obtain total numbers. Where shift working is in force the numbers of workers on each shift should be obtained, again subdivided as shown above.

### Work Pattern

The number of hours which are worked by shipyard personnel varies from country to country and should be ascertained for each shipyard. The number of hours which are used in calculating the cost of personnel must relate to information obtained upon the total salary costs and will include items such as overtime and shifts worked. These items must be included as they usually attract a premium above the base rate salary. As a large proportion of overheads are fixed, taking account of overtime and shift working can actually reduce the hourly charge rate required. Information required includes

- . number of working days per week;
- 1 number of working hours per week;
- number of days statutory, or public, holiday in a year;
- 1 number of days vacation in a year;
- 1 average number of hours overtime worked by an individual per year;
- 1 average percentage of absenteeism in a year; and
- . number of shifts worked per day.

### Man-Hours Used In production

In theory if the number of direct workers and the hours worked per year are known then the total man-hours used in producing the work in a year is the product of these figures. In practice if the actual man-hours charged against contracts is obtained and summed, there is usually a discrepancy. If there is a discrepancy the reason for it should be ascertained.

To perform the check above, the actual recorded man-hours of all of the direct workers (shipyard and subcontractors) should be obtained for each ship during the time period for which the information on ships delivered was received. If the man-hours can be obtained for each trade within each workshop, or department, then this would provide useful information for any subsequent, more detailed, investigations. The annual average direct man-hours will be obtained by summing all of the man-hours per ship and dividing by the relevant number of years.

### Financial Information

To obtain the cost of producing a CGT, full financial particulars of a shipyard are required. These particulars must include the following for the latest available financial year:

- 1 total salaries paid to the shipyard direct workers for work related to shipbuilding, including basic salary, overtime, and bonuses;
- 1 total costs of direct subcontractors employed for shipbuilding;
- 1 total salaries paid to shipyard indirect workers for work related to shipbuilding (these salaries should include the same payments as for the direct workers);
- 1 total costs of indirect subcontractors employed on shipbuilding related tasks;
- 1 total social costs of employing the above direct workers;
- 1 total social costs of employing the above indirect workers;
- 1 total cost of materials and services necessary for running the business but not chargeable to specific contracts; and
- 1 overhead costs (these should be divided into fixed and variable overheads).

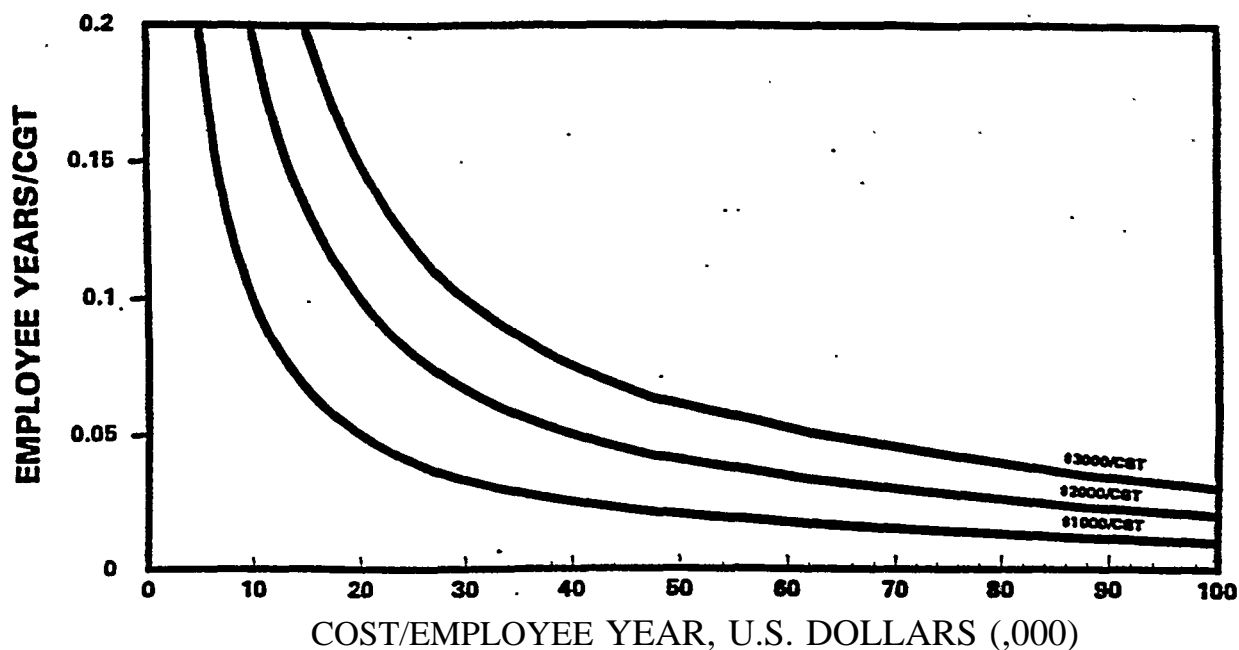
### UPDATING OF DATABASE

A database of the results of shipyard productivity and competitiveness surveys was used in this study (A&P Appledore, undated). All data in this database represents a snapshot in time and will be out of date unless it is updated. All information is dated and has the relevant exchange rate against the U.S. Dollar recorded with it. The information obtained from the shipyards surveyed for this project is among the most up to date available and was entered into the database. It was also used to help update the remaining data in the database.

### METHODOLOGY

The average annual output in terms of CGT is obtained from the ship production information. Man-hours expended in producing the above output can be calculated by using the average number of employees over the same time period as the output information in association with their working pattern. Alternatively, it may be obtained by using the actual man-hours recorded against each ship during the same time





$$\text{COST PER CGT} = \text{COST/EMPLOYEE YEAR} \times \text{EMPLOYEE YEAR/CGT}$$

Figure 1 constant cost Curves

period. The average annual man-hours expended is the total man-hours expended divided by the relevant number of years. The annual cost of employing a shipbuilding employee is derived by-first determining the annual operational cost of the shipyard as the summation of:

- 1 total annual salary cost of direct and indirect workers;
- 1 total annual social cost of employing direct and indirect workers;
- 1 total annual cost of direct and indirect subcontractors;
- 1 total annual cost of materials and services necessary for running the business but not chargeable to contracts;
- 1 annual variable overheads; and
- 1 annual fixed overheads.

The latest available figures should be used. The cost per year of employing a shipbuilding employee is the ratio of the annual operational cost of the shipyard to the total number of shipbuilding employees. The number of employees must relate to the time period for which the financial information was obtained. Total number of shipbuilding employees is used to avoid confusion caused by different definitions of direct and indirect employees.

The cost of producing a CGT is calculated as follows:

$$\begin{aligned} \text{EMPLOYEE MAN-HOURS/CGT} = \\ \frac{\text{AVG. ANNUAL MAN-HOURS EXPENDED}}{\text{AVG. ANNUAL OUTPUT IN CGT}} \end{aligned} \quad (2)$$

$$\begin{aligned} \text{EMPLOYEE YEARS/CGT} = \\ \frac{\text{EMPLOYEE MAN-HOURS/CGT}}{\text{AVG. HOURS WORKED/YEAR}} \end{aligned} \quad (3)$$

$$\frac{\text{COST}}{\text{EMPLOYEE YEAR}} = \frac{\text{EMPLOYEE YEARS}}{\text{CGT}} \quad (4)$$

The COST/CGT calculated above is in the local currency of the country with which the shipyard is located. In order to compare with other shipyards worldwide the value is converted into U.S. Dollars by multiplying by the relevant exchange rate.

To compare shipyards throughout the world a plot of employee years per CGT versus cost per employee year is used. On this graph are curves of constant cost per CGT. The calculated values for any shipyard or shipbuilding country/region can be plotted on this graph to indicate their relative performances (see Figure 1).

The value plotted on the horizontal axis only represents a snapshot in time for the various shipyards and countries since costs and exchange rates change continuously. To alleviate this problem, the dates when each data item on the graph was calculated are recorded and the salary levels and exchange rate used are noted. Salary levels in these countries are tracked so that costs can be adjusted to suit and current exchange rates are applied to obtain the latest values for the cost per employee year. Productivity will also change over time and if any reliable information is obtained about this it is also incorporated.

The overall productivity of shipyards has to be measured over long periods of time, three years for merchant shipbuilders and five years for naval shipbuilder. Two pieces of information are required in order to calculate productivity, including the output in terms of CGT and the effort in terms of man-hours required to produce it.

Information on costs is often difficult to obtain as it is commercially sensitive and requires more effort by the shipyard to produce. Some shipyards will provide the information but if they do not then recourse to other sources is made. A number of industry associations of shipbuilding countries keep track of the relevant wage rates of competitor nations. Reports of this information adjusted to account for overhead costs, can be used.

A shipyard's current competitive position is obtained by multiplying the productivity in terms of employee years required to produce a CGT by the total cost per employee year to obtain the cost of producing a CGT in U.S. Dollars.

## ESTIMATE OF CGT COEFFICIENT FOR NAVAL SHIPS

CGT Coefficients only exist for merchant ships and, as the vast majority of the current output of the U.S. shipbuilding industry is naval ships, an estimate of equivalent CGT Coefficients for such vessels is required in order to compare productivity with competitor shipyards. An estimate of such a coefficient has been produced as a part of this study. It should be stressed that this is only an estimate produced in order to place the U.S. shipyards in their relative competitive position in world shipbuilding, and should not be taken as the definitive COT coefficient for naval ships. To develop such coefficients would require a large scale study and the cooperation of naval shipbuilders worldwide.

In order to produce an estimate of CGT Coefficients for naval ships, data on 30 different vessels was used. These were all first ships in a series because they include all engineering and other non-repetitive man-hours and a significant number of merchant shipbuilding orders are for single ships. The naval ships for which information was available varied between 33m (100 ft.) Fast Patrol Craft to 196m (650 ft.) Submarine Tenders and were built in Canada, France, Germany, Italy, Spain, the U.K., and the U.S. 67% were built in Europe and 33% built in North America.

Figure 2 shows a plot of the values derived and the resultant curve drawn through them. This figure can be used to pick off the estimated CGT Coefficient for any naval ship having a GT of up to 120,000. It is stressed that the curve is based upon sparse data, but it has the advantage of varying with size of ship in the same manner as the coefficients for commercial ships.

## U.S. SHIPYARDS COMPARED TO FOREIGN COMPETITORS

As part of the study five foreign shipyards were visited and their technology levels assessed. For three of them their productivity was also derived. The foreign shipyards visited were:

- . AESA Sestao Yard, Spain;
- . Harland and Wolff, U.K.;
- . IHI Kure Yard, Japan;
- . Kvaerner Govan, U.K.; and
- . Odense, Denmark.

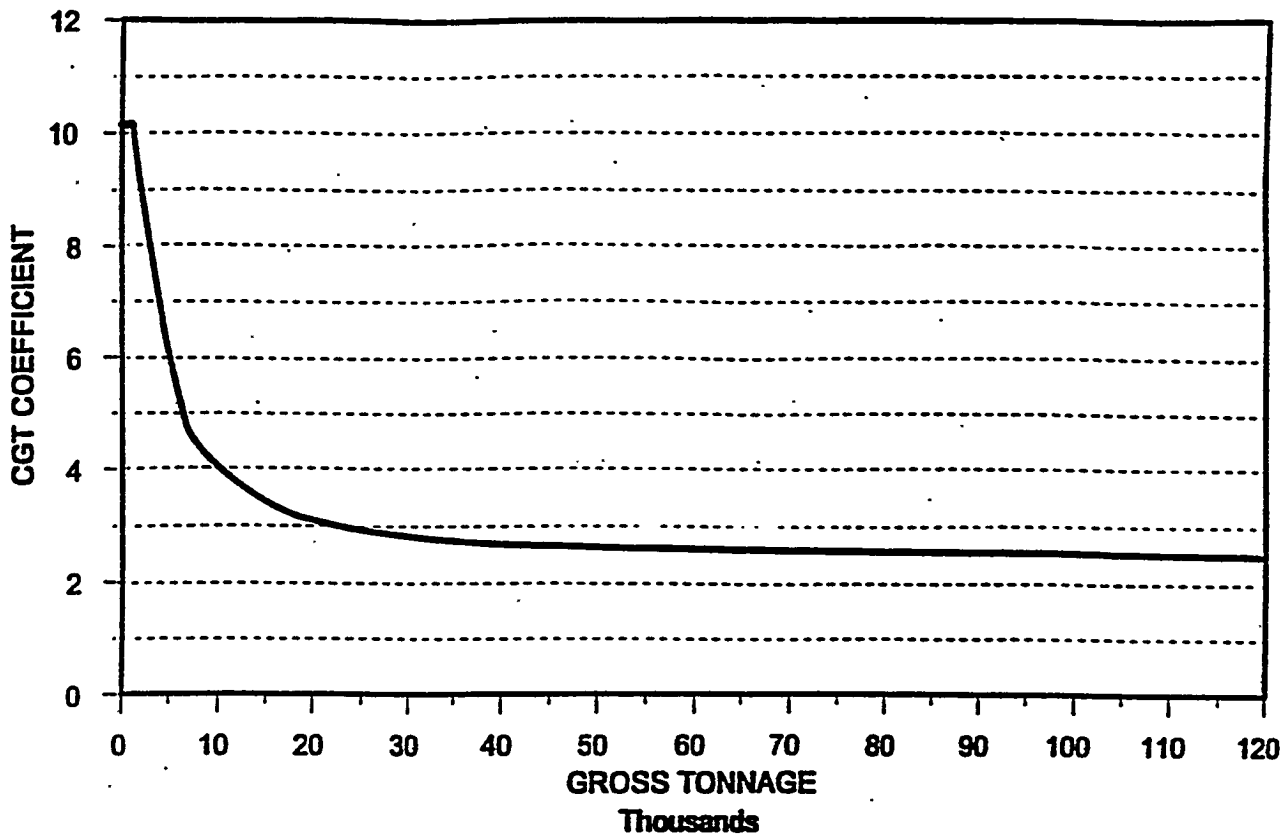


Figure 2 CGT Coefficients for Naval Vessels

These shipyards are all capable of building the ships which the four large U.S. shipyards visited can build and are thus direct competitors for building commercial ships.

#### LEVELS OF TECHNOLOGY

Three average levels of technology were calculated. These were for:

- 1 the four large U.S. shipyards visited;
- 1 the five foreign shipyards visited;
- 1 world shipyards of about the same size as the surveyed yards and which are direct competitors (excludes U.S. shipyards but includes the five foreign shipyards visited).

The average values for each of the surveyed elements of the four large U.S. shipyards and the five foreign shipyards are shown in Table I, together with their overall technology levels. Table I shows that the four large U.S. shipyards have an average technology level of 3.4, while the five foreign yards averaged 4.0.

The spread of overall technology levels for the surveyed yards is shown in Table II.

Table II shows that the U.S. shipyards are grouped very closely together in terms of technology level, and that they are as good as the lowest two of the foreign shipyards surveyed. However, the best three competitors which were visited are some five to ten years ahead in terms of shipbuilding technology. At least one of the foreign competitors having a low technology level is known to be striving to rapidly improve this with external assistance.

Technology levels of shipyards which are direct competitors to U.S. shipyards, including the five foreign shipyards surveyed, average 3.5, with a range of from 1.8 to 4.6. Thirty five shipyards were considered, from the following areas:

- 1 Croatia;
- . Far East, excluding Japan and Korea;
- 1 Finland;
- . Japan;

Label	Activity	Technology Level			Weighted Level	
		US Shipyards	Foreign Shipyards	Weighting	US Shipyards	Foreign Shipyards
A1	Plate stockyard and treatment	2.9	2.9	0.500	0.145	0.145
A2	Stiffener stockyard and treatment	2.8	2.9	0.040	0.112	0.116
A3	Plate cutting	3.8	4.0	0.090	0.342	0.360
A4	Stiffener cutting	2.1	3.4	0.080	0.168	0.272
A5	Plate and stiffener forming	2.8	3.2	0.080	0.224	0.256
A6	Subassembly	2.6	3.4	0.120	0.312	0.408
A7	Flat unit assembly	2.9	3.2	0.130	0.377	0.416
A8	Curved and corrugated unit assembly	2.9	3.4	0.150	0.435	0.510
A9	3D unit assembly	3.1	3.9	0.110	0.341	0.429
A10	Superstructure unit assembly	3.0	3.4	0.100	0.300	0.340
A11	Outfit steelwork	3.0	4.1	0.050	0.150	0.205
<b>A</b>	<b>STEELWORK PRODUCTION</b>			<b>0.156</b>	<b>2.908</b>	<b>3.457</b>
B1	Pipework	3.3	3.3	0.190	0.627	0.627
B2	Engineering	2.8	3.0	0.130	0.364	0.390
B3	Blacksmiths	3.3	3.8	0.050	0.165	0.190
B4	Sheet metal work	2.9	4.3	0.150	0.435	0.645
B5	Woodworking	3.5	3.7	0.100	0.350	0.370
B6	Electrical	3.5	4.0	0.090	0.315	0.360
B7	Rigging	3.0	3.5	0.050	0.150	0.175
B8	Maintenance	3.8	3.6	0.060	0.228	0.216
B9	Garage	3.6	3.8	0.040	0.144	0.152
B10	General storage	3.6	4.4	0.070	0.252	0.308
B11	Auxiliary storage	3.9	4.5	0.070	0.273	0.315
<b>B</b>	<b>OUTFIT PRODUCTION AND STORES</b>			<b>0.115</b>	<b>3.303</b>	<b>3.748</b>
C1	Module building	3.3	3.9	0.180	0.594	0.702
C2	Outfit parts marshalling	5.0	4.0	0.200	1.000	0.800
C3	Pre-erection outfitting	3.4	4.1	0.210	0.714	0.861
C4	Block assembly	3.8	4.2	0.220	0.836	0.924
C5	Unit and block storage	3.6	4.7	0.070	0.252	0.329
C6	Materials handling	3.6	3.7	0.120	0.432	0.444
<b>C</b>	<b>OTHER PRE-ERECTION ACTIVITIES</b>			<b>0.167</b>	<b>3.828</b>	<b>4.060</b>

Table I Summary of Average Technology Levels for Large U.S. Shipyards and Visited Foreign Competitors

Label	Activity	Technology Level		Weighting	Weighted Level	
		US Shipyards	Foreign Shipyards		US Shipyards	Foreign Shipyards
D1	Ship construction	3.0	3.7	0.090	0.270	0.333
D2	Erection and fairing	2.8	4.0	0.100	0.280	0.400
D3	Welding	3.3	3.6	0.100	0.330	0.360
D4	Onboard services	3.4	4.4	0.060	0.204	0.264
D5	Staging and access	2.6	3.5	0.080	0.208	0.280
D6	Pipework	3.5	4.1	0.100	0.350	0.410
D7	Engine room machinery	3.3	4.5	0.050	0.165	0.225
8	Hull engineering	3.4	4.5	0.050	0.170	0.225
9	Sheet metal work	3.5	4.5	0.040	0.140	0.180
10	Woodwork	2.5	3.7	0.040	0.100	0.148
11	Electrical	3.1	4.0	0.070	0.217	0.280
12	Painting	2.6	3.5	0.080	0.208	0.280
13	Testing and commissioning	4.3	4.7	0.090	0.387	0.423
14	After launch	3.1	3.5	0.050	0.155	0.175
SHIP CONSTRUCTION				0.167	3.184	3.983
E1	Layout and material now	26	3.1	0.320	0.832	0.992
E2	General environmental	3.1	3.5	0.300	0.930	1.050
E3	Lighting and heating	3.5	3.1	0.150	0.560	0.496
24	Noise, Ventilation and fume extraction	28	3.5	0.220	0.616	0.770
LAYOUT AND ENVIRONMENT				0.083	2.938	3.308
G1	Ship design	3.1	4.0	0.120	0.372	0.480
G2	Steelwork drawing presentation	3.3	4.4	0.100	0.330	0.440
G3	Outfit drawing presentation	3.3	4.5	0.100	0.330	0.450
G4	Steelwork coding system	4.5	5.0	0.070	0.315	0.350
G5	Parts listing procedures	4.5	5.0	0.100	0.450	0.500
G6	Production engineering	3.1	4.0	0.330	0.403	0.520
G7	Design for production	3.1	4.1	0.160	0.496	0.655
G8	Dimensional and quality control	3.0	4.1	0.130	0.390	0.533
G9	Lofting methods	4.0	4.5	0.090	0.360	0.405
DESIGN/DRAUGHTING/PRODUCTION ENGINEERING/LOFTING				0.166	3.446	4.334

Table I (cont.)

Label	Activity	Technology Level			Weighted Level	
		US Shipyards	Foreign Shipyards	Weighting	US Shipyards	Foreign Shipyards
H1	Organisation	2.5	4.4	0.120	<b>0.300</b>	<b>0.528</b>
H2	Contract scheduling	3.8	4.8	<b>0.060</b>	<b>0.228</b>	<b>0.288</b>
H3	Steelwork production scheduling	4.4	4.9	0.070	<b>0.308</b>	<b>0.343</b>
H4	Outfit production scheduling	4.4	4.8	0.080	<b>0.264</b>	<b>0.288</b>
H5	<b>Outfit installation scheduling</b>	4.5	4.9	<b>0.070</b>	0.315	<b>0.343</b>
H6	Ship construction scheduling	4.4	4.8	0.070	0.308	<b>0.336</b>
H7	Steelwork production control	4.0	4.6	0.070	<b>0.280</b>	<b>0.322</b>
H8	Outfit production control	4.0	4.6	<b>0.070</b>	0.280	<b>0.322</b>
H9	Outfit installation control	4.0	4.6	0.080	0.320	<b>0.368</b>
H10	Ship construction control	4.0	4.6	0.080	<b>0.320</b>	<b>0.368</b>
H11	stores control	4.3	4.8	0.070	0.301	<b>0.336</b>
H12	Performance and efficiency calculations	4.6	4.9	0.050	0.230	0.2451
H13	Computer applications	3.8	4.0	0.050	0.190	0.200
H14	Purchasing	4.9	4.8	0.080	0.392	0.384
H	ORGANISATION AND OPERATING SYSTEMS			0.146	<b>4.036</b>	4.671
SHIPYARD TECHNOLOGY LEVEL = $\frac{\sum H}{A}$ (Sum of Products x Group Weighting)				1.000	<b>3.409</b>	<b>3.989</b>
					3.4	4.0

Table I (cont.)

1 Korea;  
1 Poland;  
. Russia;  
. South America;  
. Ukrain; and  
1 West Europe.

The U.S. shipyards are therefore operating at about the average technology level of their foreign competitors but a cause for concern is that all shipyards operating at a lower level of technology have very much lower labor rates. This also applies to Korean shipyards which have a higher level of technology than the U.S. shipyards.

DETAILED DIFFERENCES IN TECHNOLOGY  
L E V E L S

The relative strengths and weaknesses of the U.S. shipyards have been compared with the five foreign shipyards surveyed and these are discussed below. The comments relating to the current good practices of the competitors relate to all of the shipyards worldwide which have high levels of technology. This discussion is based on the actual observations of work being performed at the five U.S. shipyards during April, 1994. All the shipbuilding was for U.S. government orders (primarily U.S. Navy) or other militay vessels. The work practices in the U.S. yards for military vessels are thus being compared to best commercial shipbuilding practices worldwide.

OVERALL TECHNOLOGY LEVEL  
YARD US. YARDS FOREIGN YARDS

1	3.2	3.0
2	3.4	3.3
3	3.4	4.1
4	3.5	4.4
5	.	4.5

Table II Overall Technology Levels of Surveyed Yards

At the group level the U.S. shipyards have a lower level of technology for each area The differences can broadly be divided into large (over 0.75), medium (0.4 to 0.75) and small (less than 0.4).

LARGE DIFFERENCES

Ship Construction & Outfit Installation

There is no element of this group in which the U.S. shipyards are the equal of the foreign yards. The following elements all have a technology level at least 0.9 lower than the foreign shipyards.

Erection and Fairing All U.S. yards leave excess stock upon the blocks which arc to be erected. Accuracy control should be developed to the level where this can be avoided. Although in most yards the shell plating on blocks was fair, the internal decks and longitudinal bulkheads suffered from a great deal of distortion, leading to excessive times for fairing. Welded fairing aids are also used extensively.

(Onboard Services There was some evidence of pre-planned routing of services in the U.S. shipyards and the leading of the services overhead so that the decks were clear. However, the foreign shipyards have formal plans for routing of services and arranging them in a modular form so that each can be expanded or withdrawn without disruption to the remaining ones. The foreign yards also required less onboard services because a larger percentage of the work had been performed prior to erection.

Staging and Access The amount of staging used in the U.S. shipyards was far in excess of that used in the foreign shipyards and a large amount of it was of the scaffolding and wooden plank type. The requirement for a good deal of staging was avoided by the foreign yards since they paint blocks before hull erection and subsequently use "cherry pickers," or similar, to paint in way of berth joints, or even to paint the complete exterior shell before launch. The pre-planning and performing of work at the unit/block stage which can be accessed without the need for staging also reduces the requirement for staging. The foreign shipyards visited were better than the U.S. shipyards at this.

Engine Room Machinery Although a considerable amount of pre-erection outfitting in the machinery spaces occurs at all of the U.S. shipyards surveyed, it falls well below that achieved in the foreign shipyards visited. One reason given by the U.S. shipyards is that the machinery spaces in the naval ships which they are building are extremely cramped and it is difficult to get things in. In fact, this makes it more imperative that as much machinery installation and other outfit activities as possible take place while the spaces are open and easily accessed. A number of the foreign shipyards also have formal self-checking statistical process control systems which means that their processes are under control (in the statistical meaning of the phrase).

Hull Engineering The comments on Engine Room Machinery all apply equally to Hull Engineering.

Sheet Metal Work Apart from some ventilation ducting there is very little sheet. metal work installed before launch in U.S. shipyards. This not the case in the foreign shipyards, where sheet metal for use in accommodation spaces is often installed on-unit. A good deal of the ventilation ducting installed on block is actually fitted in the overhead position with the block in its final orientation. This work needs to be performed earlier, when the deckhead is in the

inverted position. Again, a number of the foreign shipyards have formal self-check statistical process control systems in place.

**Woodwork** Although a number of the U.S. shipyards subcontract the making of furniture and produce joiner panels pre-cut to size in the workshop, this is all installed after launch. As a minimum, all foreign shipyards visited erected the superstructures and deckhouses almost completely outfitted. Modular cabins and sanitary spaces were also used to varying degrees.

**Electrical** All of the U.S. shipyards visited pre-cut cable to approximate size before installation, but there was very little cable pulling performed before launch. Some of the major electrical equipment was installed before launch, but not hooked up. The foreign shipyards had all major electrical equipment installed and hooked up before launch, had cables pulled on block (to be completed/continued on adjacent blocks when erected) and smaller items, such as lights, fitted. Subsequent use was made of the ship's lights (powered by shore supply) in order to prevent a temporary service being installed.

**Painting** A number of problems were noted with painting in U.S. shipyards, of which three are most important. First, primers were not usually of a weld through type or were applied too thickly to allow welding to take place upon them. At present this is not a major problem due to the fact that initial stiffener locations marked by the burning machines are ground off and remarked by hand after plates have been joined to form panels. This is because the initial markings do not take account of weld shrinkage. Secondly, due to the length of time spent in storage or being worked upon after the treatment line, all yards perform a second blast and prime operation upon blocks. This prevents any outfit items which would be damaged by blasting being installed prior to this stage. After this stage they are installed with the block in its final orientation. No foreign shipyard performed this second blast and prime operation. They merely touched up primer damaged during the production operations and cleaned the structure prior to applying the finished coatings. Only if a contract required it (e.g., for product tankers' cargo tanks) would a second surface preparation operation would take place. Finally, most finish painting in U.S. yards takes place after hull erection and launch and at present is associated with a large amount of staging.

## Design/Drafting/Production Engineering/Lofting

This group is the one in which the greatest average difference between the U.S. shipyards and the foreign shipyards occurs. The minimum difference in technology levels is 0.5 and, even where the U.S. shipyards score highly (Steelwork Coding and Parts Listing) the competitors have a higher level. It is an example of where an industry has superior equipment but does not use it as effectively as competitors use less sophisticated equipment. The foreign shipyards have concentrated on getting methods correct before assessing whether they require the use of computers to support them. All elements discussed below have a difference in technology between U.S. yards and the foreign shipyards of at least 0.9.

**Ship Design** Although most U.S. shipyards surveyed have some design capability they are all severely limited in the commercial area. There is very little knowledge or information about modern merchant ship design, statutory requirements or classification society requirements in the whole of the U.S. shipbuilding industry.

**Steelwork Drawing Presentation** The major difference in the presentation of the drawings is that the foreign shipyards present the information to support the manner in which the work is to be performed and, as they produce steelwork in work stations, then the drawings are smaller and only include the information necessary to undertake the work at the relevant work station. The smaller drawings are easier to check so less engineering errors end up on the shop floor. Engineering errors were mentioned by the production departments of U.S. shipyards as a major problem.

**Outfit Drawing Presentation** The U.S. shipyards produce large, multi-trade drawings which cover a number of blocks or zones. This applies to both manufacturing and installation information. Usually both the manufacturing and installation information is contained on the same drawing. The foreign shipbuilder tend to produce separate drawings for the manufacture of work pieces and for their installation. Installation drawings are related to where the pieces are installed and could be work station related for installation in a steel shop, or zone/stage oriented for installation on-block or on-board. Installation drawings will also include all items to be installed in a workstation/zone /stage by all trades, or installers.



**Production Engineering** All U.S. shipyards apply production engineering techniques to their work and have good communication between the Engineering, Production Engineering, Planning, and Production departments. The major advantage which the foreign shipyards have is that they all have developed standards (both physical and procedural) which apply to merchant ships and which have been accepted by flag states and classification societies. These standards have been extensively production engineered and refined over a period of time.

**Design for Production** An effort is made in U.S. shipyards to include design for production in ships which have become contracts. This needs to be moved to the earliest stages of pre-bid design. There is a lack of knowledge of modern production techniques and of applying design for production among the naval architects who perform the initial designs in U.S. shipyards. The foreign shipyards have advanced the design for production of outfit items to a far greater extent than the U.S. shipyards.

**Dimensional and Quality Control** All of the surveyed U.S. shipyards have started the collection of dimensional information in their steelwork areas, but no shipyard has had the information analyzed in order to produce work instructions with acceptable tolerances for any stage in the process. The collection of data on the outfitting side has not been started yet. The foreign shipyards have all collected and analyzed information on their steelwork production processes and can be said to have them under control. Comprehensive procedures and standards have been developed and implemented. The result is greatly reduced rework and minimal excess stock on steel work. A great help in collecting information and keeping the processes under control is the establishment of work stations which produce identical, or very similar, items repeatedly. Foreign shipyards have gone onto apply the technique to outfit work and have largely succeeded in bringing this work under control. The foreign shipyards have instituted a system of self-checking at every stage and continually assessing whether the processes are still in control. The system is supported by the Quality Control and/or Accuracy Control Department in their yards. Continuous improvement programs are also in place.

## MEDIUM DIFFERENCES

### Steelwork Production

In no element of this group are the U.S. shipyards superior to their 'competitor, although they are equal in one (Plate Stockyard). The major differences exist in the following elements.

**Stiffener Cutting** This is almost always performed by hand marking followed by hand burning.

**Sub-assembly** These are produced in random locations in workshops which also produce a variety of other work such as outfit steel items.

**3D Unit Assembly** A variety of practices apply including assembling where space is available, adding individual stiffeners to webs and pulling shell plate around, adding curved, stiffened panels to webs (the latter two methods at the same yard), erection outside, leaving excess stock on plates, and using welding procedures which result in significant distortion.

**Outfit Steelwork** Outfit steelwork is often produced in steel workshops in locations determined by where there is space available. No group technology is used.

### Outfit Production and Stores

In the maintenance element of this group the U.S. shipyards are superior to the foreign yards. In most other elements they are very close, but for the following two elements there are significant differences.

**Sheet Metal Work** The sheet metal workshops in the U.S. shipyards are all extremely well equipped but none is organized on a group technology basis. They all appear to produce items which could probably be purchased cheaper from outside suppliers.

**General Storage** This was a somewhat surprisingly large difference, given that the warehouses in the U.S. shipyards are large, well run, departments. The difference is that each yard has huge warehouses in which a tremendous amount of material and equipment is held, whereas the competitors hold low levels of stock and some have developed really efficient just in time delivery of the required materials and equipment.

### Organization & Operating Systems

All the shipyards surveyed scored highly in this group, but the foreign yards were consistently better, apart from purchasing in which the U.S. shipyards were marginally ahead. The two areas in which the

overseas competitors are significantly ahead are detailed.

**Organization of Work** This relates to the flexibility of the work force and the manner in which it is supervised. It was found that, although there are signs of trade flexibility and multi-skill training in the U.S. yards, work is still mainly done on a trade related basis. Supervision is also on a trade basis. All of the foreign competitors have a far more flexible, multi-skilled work force and agreements in place which will allow the full benefits of this to be achieved. The presence or absence of unions seemed to have little impact on these differences. The foreign shipyards also perform the work in workstations or zones and supervision is related to zones and not to trades.

**Contract Scheduling** This is actually quite well done in the U.S. shipyards but it is extremely well done by their foreign competitors. The major difference is that the foreign shipyards link strategic planning and tactical planning using computer systems which allow direct interaction between the two levels.

## SMALL DIFFERENCES

### Other Pre-Erection Activities

Although the average levels for the overall group are fairly close, there are large differences in the individual elements. These occur in Outfit Parts Marshaling, which is one of only four elements in which U.S. shipbuilding is more advanced than their competitors, and Unit a Block Storage where the competition is more advanced than the U.S. shipyards. The group as a whole has a fairly high technology rating for both industries.

**Outfit Parts Marshaling** This is particularly good in the U.S. shipyards due to the fact that planning issues to stores and workshops timely lists of what items are required when and where, which allows these departments to produce "kits" or "pallets" of the required items.

**Unit and Block Storage** This is the element in this group in which the competitors are furthest ahead. It is a problem in most of the U.S. shipyards visited due to lack of area and also to the length of time which blocks spend in storage.

### Layout and Environment

This group is rated as fairly low technology for both industries examined, and the differences within the group are all in the medium range. One element, Lighting & Heating, has a higher technology rating for the U.S. shipyards and this reduces the overall difference. With the exception of one U.S. shipyard and two of the foreign shipyards, all layouts and resulting material flows are constrained by the site and the ad hoc manner in which the yards have developed over the years.

## COMPARISON WITH 1978 SURVEY

The technology survey of the U.S. shipyards which was conducted in 1978 did not apply weightings to the individual elements which were included in the study, so to compare like items the currently used weightings have been assigned to the results of the earlier study (Lowry, 1980). The results for the groups are shown in Table III below. Certain elements are now included in different groups than they were in the 1978 study, e.g., E2 E3 and E4 were previously F1, F2 and F3.

The results in Table III show that in 16 years the average technology level in U.S. shipyards has increased by 0.9, from 2.5 to 3.4, while the foreign shipyards have increased by 1.1, from 2.9 to 4.0, i.e., the gap has widened slightly. The maximum attainable technology level in 1978 was 4.0 while the current highest level is 5.0, the increase in the level being judged to have occurred by 1990, over 12 years. Increases in average technology levels in the two studies could therefore be expected to be between 1.0 (5.0-4.0) and 1.25 (5.0/4.0). Both of the actual recorded increases are within the expected ranges, but significantly, that for the foreign yards is greater.

A brief examination of the changes in the groups shows the following. For Group A, Steelwork Production, the actual level of technology at present in the U.S. shipyards is now at the level it was in the foreign shipyards in 1978. However, the U.S. shipyards have actually progressed more than their foreign competitors, the average differences being 0.66 and 0.55 respectively. Both sets of yards have made the most progress in two areas, 3D Unit Assembly and Outfit Steelwork. The increases for 3D Unit Assembly are both 1.0, but the U.S. yards moved from 2.1 to 3.1 while the competitors changed from 2.9 to 3.9. In Outfit Steelwork the U.S. yards increased by 1.2, from 1.8 to 3.0, and the competitors rose by 1.6, from 2.5 to 4.1.

GROUP	1978 SURVEY			1994 SURVEY		
	U.S. SHIPYARDS	FOREIGN SHIPYARDS	DELTA	U.S. SHIPYARDS	FOREIGN SHIPYARDS	DELTA
A Steelwork Production	2.25	2.91	0.66	2.91	3.46	0.55
B Outfit Production and Stores	2.36	2.43	0.07	3.30	3.75	0.45
C Other Pre-Erection Activities	2.06	2.76	0.70	3.83	4.06	0.23
D Ship Construction	2.48	2.86	0.38	3.18	3.98	0.80
E Layout and Environment	2.33	2.89	0.56	2.94	3.31	0.37
G Design/Drafting/ Production Eng/Loft	2.92	3.17	0.25	3.45	4.33	0.88
H Organization and operating systems	2.98	3.03	0.05	4.04	4.67	0.63
OVERALL TECHNOLOGY LEVEL	2.5	2.9	0.4	3.4	4.0	0.6

Table III 1978 Survey Results Compared To 1994 Survey Results

Group B, Outfit Production and Stores had an average progress for both sets of yards of about what was expected, 0.94 for the U.S. yards and 1.32 for the competitors. U.S. shipyards have made the best progress in:

Electrical	1.2
General Storage	1.3
Pipework	1.3
Maintenance	1.4

while the foreign yards produced the highest gains in:

Woodworking	1.4
Electrical	1.6
General Storage	2.0
Auxiliary Storage	2.1
Sheet Metal Work	2.2

In pipe work the U.S. yards have made enough progress to be level with their competitors and in maintenance they have actually drawn ahead. In electrical and rigging they were about the same level in 1978 but have fallen behind by 0.5 now.

Group C, Other Pre-Erection Activities, is the group in which, on average, the most progress has been made, with the U.S. shipyards advancing by 1.77

against their competitors' 1.30. The gap has narrowed from 0.70 in 1978 to 0.23 at present. This is a significant group to make progress in as it demonstrates that more work is being performed in workshops rather than on the building berths. The major advances have been made in:

Block Assembly	1.6
Module Building	1.7
Outfit Parts Marshaling	3.1 to 5.0

In Group D, Ship Construction, the foreign shipyards have increased their technology level by an expected amount, 1.12 while the U.S. yards have improved by 0.70. The only improvements of an anticipated amount in the U.S. shipyards were in:

Welding	1.0
Pipework	1.1
Hull Engineering	1.2

During the period the foreign shipyards made significant improvements in

Pipework	1.5
Engine Room Machinery	1.6
Hull Engineering	1.7
Testing and Commissioning	1.9

In the painting area the U.S. shipyards have virtually stood still, only improving by 0.1.

Neither set of shipyards has shown a large improvement in Group E, Layout and Environment although the U.S. yards moved more than their competitors, 0.61 compared to 0.42. For both sets the element Layout and Material Flow has only increased by 0.1, indicating that the shipyard sites are still constraints to an efficient layout and material flow.

Group G, Design/Drafting/ Production Engineering/Lofting is one in which the foreign shipyards have made twice as much progress as the U.S. shipyards, 1.16 compared to 0.53. This was from a fairly close position in the 1978 study, U.S. yards at 2.92, foreign yards at 3.17. The competitors have made the largest progress in:

Steelwork Dwg Presentation	1.3
Lofting Methods	1.3
Steelwork Coding Systems	1.5
Outfit Dwg Presentation	1.6
Parts Listing Procedures	1.9

Only in Lofting Methods have the U.S. shipyards made comparable progress, 1.2. In three areas, Steelwork Coding System, Parts Listing Procedures and Dimensional and Quality Control, the U.S. yards have lost leads they had. In Dimensional and Quality Control they are recorded at a lower level than in the 1978 survey, 3.0 compared to 3.2.

The two sets of shipyards studied in 1978 came out with identical technology levels in Group H, Organization and Operating Systems, 3.0. However, in the intervening 16 years the U.S. yards have improved by 1.06, while the foreign yards have increased their technology level by 1.64. The increase by foreign shipyards was gained by an almost uniform increase in every element of the group, while there were large variations in the changes of the U.S. shipyards. The largest increases produced by the U.S. yards were:

Contract Scheduling	1.3
Outfit Prod Scheduling	1.5
Outfit install Scheduling	1.6
Purchasing	1.9

In Purchasing the U.S. yards have actually overtaken their competitors by a small amount, 4.9 to 4.8.

## PRODUCTIVITY

Using the information provided by the U.S. shipyards and three of the foreign shipyards, it was possible to estimate their productivities in terms of total employee man-hours required to produce a CGT. The world average productivity for similar sized shipyards (excluding U.S. shipyards) was developed.

Because the U.S. shipyards are currently building naval ships and relatively few of these are delivered annually, the output from each of the four U.S. shipyards was obtained over five years in order to establish a reliable average yearly value. The total output of the four shipyards visited over the past five years in terms of CGT and the man-hours required to produce it are shown in Table IV. The CGT produced was calculated using the estimated curve of CGT Coefficients shown in Figure 2.

TOTAL OUTPUT CGT	REQUIRED TOTAL W - HOURS
<b>1,683,671</b>	<b>314,274,641</b>

Table IV U.S. Shipyards Total Output and Required Man-hours 1989-1993

The average productivity over the period was 184.8 mh/CGT, with a range for individual shipyards of 237 mh/CGT to 119 mh/CGT. This probably presents a worse picture for the U.S. shipyards than actually exists, due to the fact that two of the yards considered undertook a significant amount of ship repair and conversion work. Also, some of the yards have "planning yard" and other white collar Navy support activities that produce spent man-hours without producing additional CGTs.

The three foreign shipyards for which productivity was measured were assessed over the previous three years. This was because merchant shipbuilders produce a greater number of ships per year and a reliable average annual output can be obtained over a shorter period than required for naval shipbuilders. The total output of the three shipyards in terms of COT and the man-hours required to produce them are shown in Table V.

The average productivity over the period was 40 mh/CGT, with a range for individual shipyards of 69 mh/CGT to 17 mh/CGT. Information on similar sized

**YEAR TOTAL OUTPUT REQUIRED TOTAL  
CGT MAN-HOURS**

<b>1991</b>	358,960	13,589,511
1992	380,720	15,781,367
1993	348,090	14,466,253
<b>TOTALS 1,087,770</b>		<b>43,837,131</b>

Table V Three Foreign Shipyards Total Output and Required Man-hours 1991-1993

shipyards to the U.S. yards (but excluding the U.S. yards) indicates the average productivity is 88 mh/CGT with a range of from 180 mh/CGT to 17 mh/CGT.

**COMPETITIVENESS**

The competitiveness of the U.S. shipbuilding industry has been assessed in terms of the cost of producing a CGT compared with the same measure for its competitors. The competitors considered are again the three foreign shipyards which were visited and for which the productivity was calculated, plus the other world shipyards considered to be competitors and for which data was available.

In order to calculate the cost of producing a CGT, the effort in terms of employee man-years required to produce a CGT is multiplied by the total annual cost of employing a shipbuilding worker. This is produced for each individual shipyard and the average obtained by dividing the sum by the number of yards. The results are shown in Table VI.

**KEY EVENT TIME SCALES**

The average key event time scales for European competitors building merchant ships are shown in Figure 3 for various ship types and sizes. Ships considered are all first in a series (or one ship contracts). The best Japanese shipyards will have total time scales of about 80% of the European figures. Since the U.S. shipyards were not building merchant ships, the actual competitive position cannot be ascertained, but the information will indicate time scales which must be attained in order to become competitive. There is a clear correlation between time scales and cost, and thus competitiveness is determined by a combination of these interrelated variables.

**RECOMMENDED AREAS TO TARGET IN ORDER TO INCREASE COMPETITIVENESS**

There are a number of areas of improvement that should be targeted by the U.S. shipbuilding industry. These are presented below, in two categories, for most important and secondary areas.

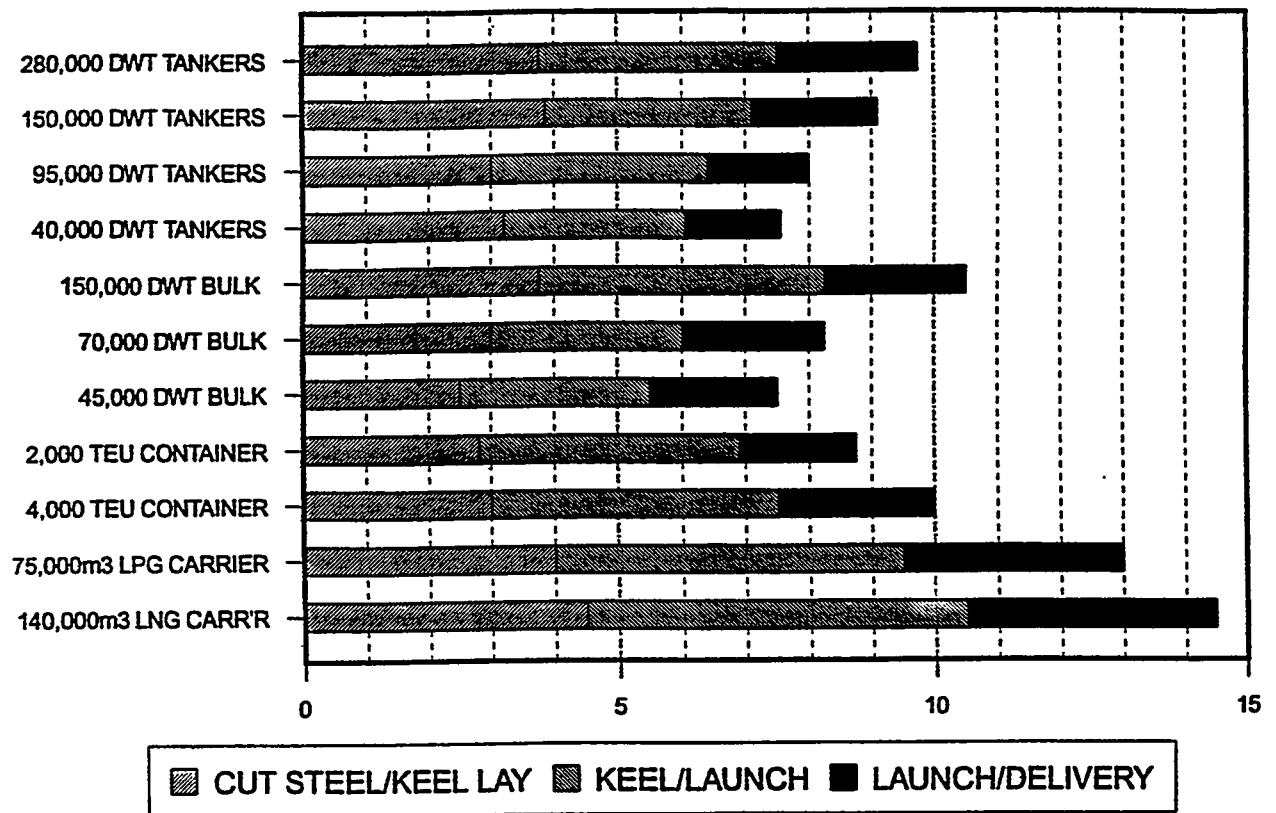
**Critical Areas for Improvement**

**Business Plan**

The U.S. shipyards must focus on the product range which they intend to build and determine their capacity, targeted output and build cycles. They also need to develop targets for costs and a pricing policy.

	U.S. YARD AVERAGE	VISITED FOREIGN AVERAGE	ALL FOREIGN AVERAGE	ALL FOREIGN RANGE
<b>MAN-HOURS WORKED PER YEAR</b>	1,829	1,805	1,963	1\$50-2,600
<b>MAN-HOURS/CGT</b>	184.8	40.0	88.0	17.0 -180.0
<b>COST/EMPLOYEE YEAR</b>	\$52,500	\$63,455	\$48,690	\$11,290 - \$104,960
<b>COST/CGT</b>	\$5,314	\$1,121	\$1,296	S697 - \$1,653

Table VI Competitiveness Comparison



NOTE:- ALL TANKERS ARE DOUBLE HULLED

Figure 3 Current Best European Build Cycle Times, Months

### Shipbuilding Policy

Once the target product mix has been determined then the optimum organization and methods must be developed in order to produce them in the most cost effective manner. A shipbuilding policy should address facilities development, productivity targets, ship definition strategy, production organization and methods, planning and contract procedures, and make, buy or subcontract policies. Successful foreign competitors have first rationalized the shipbuilding system before addressing significant facilities developments.

### Marketing

Marketing must target the owners of the ship types and sizes which are identified in the business plan in a proactive manner. These owners should then be visited to inform them what the shipyard can offer to satisfy their requirements.

### Design and Engineering

It is strongly recommended that all shipyards have their own design and engineering departments sufficient to fulfill their needs.

If designs do not include "design for ease of production" and take account of a yard's facilities and production methods, shipbuilding will be a great deal more costly and time consuming.

Engineering information needs to be produced on time and in the sequence specified by the planning department and should contain information which reflects the manner and place in which the work is to be performed. It should also be produced in accordance with a ship definition strategy.

It is unlikely that an outside organization could satisfy all of the above requirements. If they are not met then the shipbuilding process is not under control.

There is a lack of experience in modern merchant ship operations, design, regulations and the associated up to date building methods among naval architects and engineering staff in the U.S. shipbuilding industry. This expertise is essential and needs to be acquired quickly if the industry hopes to successfully penetrate the commercial markets.

#### **Total Quality Management and Accuracy Control**

U.S. shipyards have been slow to implement total quality management (TQM) principles and to adopt accuracy control procedures. TQM has proven to be a requirement in any manufacturing system that requires input from all levels of the organization in order to continuously improve productivity. World class shipyards employ TQM in some form, including training from top to bottom in the organization.

The need for accuracy, based on statistical techniques is described in the discussions of steel, outfit and painting processes. Accuracy control is directly related to improvements in cycle time, a key factor in international competitiveness.

#### **Material Management**

U.S. shipyards do not employ just in time approaches to material management. This includes identification, purchasing, warehousing, marshaling, handling and assembling. Overseas shipyards control costs by the application of this manufacturing philosophy. Significant waste, rework, and monitoring is the result of the lack of just in time material management.

#### **Purchasing**

The yards need to build up a database of suppliers of equipment for merchant ships, together with the means of recording their performance for future use. These suppliers should be worldwide. Continuing efforts to improve supplier relationships are critical for achieving worldwide competitiveness.

Purchasing should aim for just in time delivery of materials and equipment to the shipyard in order to reduce capital tied up in stored goods and the storage area necessary. Moving to the universal application of this practice, even for U.S. Navy or other government work, will provide long term benefits to both the shipyards and the government. Suppliers are becoming used to just in time deliveries that are being required by all industries, which should help U.S. shipyards in these efforts.

#### **Second Blast and Prime Operation**

This should be completely eliminated from the shipbuilding process. It does not occur in any modern merchant shipbuilding yard and should be unnecessary. The elimination of this operation will allow additional outfit materials and equipment to be installed on unit, or on block, earlier than at present. This is because at present items which would be damaged by blasting have to be omitted until after the operation takes place.

#### **Outfitting**

Only one of the U.S. shipyards visited had collected data on an outfit manufacturing or installation procedure in order to have them analyzed as part of a self-checking statistical process control system. This should be addressed, as all aspects of ship production must be brought under control in the statistical meaning of the word.

Outfitting should be performed earlier in the building process so that, for example, deckheads are outfitted while they are in an inverted position in a workshop. Too much deck level outfitting occurs on block while the block is in its final orientation. Equipment should be installed "blue sky" and not moved in horizontally when the block ring has been completed. More electric cabling could be installed on unit and on block, with excess lengths which have to be run to adjacent, or further, blocks left coiled in place.

The yards should develop standard equipment units for merchant ships and incorporate them into the designs for these ships. The framework for such units should support the units without the need for temporary stiffening, which occurs at present.

Outfit workshops should be organized on a group technology basis with groups of similar work being produced in dedicated workstations using standard procedures and tools.

The use of welded studs and bolts for the attachment of pipe hangers, cable ways, vent trunks, electric lights and other outfit items should be greatly extended.

When a ship is in the water the required services should be led in planned routes, kept clear of the deck, and arranged in modular form to allow for removal or expansion without interruption to the remainder of the services. The early hookup of the ship's electric lights will allow them to be used via shore supply in order to reduce the services required.

### **Painting**

This is an area where Japanese shipyards are making large investments in order to improve productivity and quality. Painting should be so organized that finish painted blocks go to the ship assembly berth. The blocks should be painted in paint cells or similar. During the build process any damaged primer should be wire brushed and touched up to maintain protection.

### **Mixing Naval and Merchant Ship Construction**

There is some circumstantial evidence to suggest that it is counter productive to build commercial/merchant ships (of whatever type) and military ships in the same shipyard using the same engineering and production personnel. While some internationally competitive shipyards successfully mix merchant and naval shipbuilding, most world class shipyards concentrate totally on merchant ship construction.

In principle, some types of small to medium size merchant ships have some characteristics that are similar to those of naval combatant ships of comparable size. The important characteristics are (1) where the functional role of the vessel requires extra,

specialist **crew** members to operate the vessel while it is underway, (2) it has special, often technically sophisticated, on-board engineering systems over and above those required to navigate and provide the propulsion and crew accommodation services, and (3) there is a high "packing density" of engineering systems in compact machinery spaces.

Commercial vessels that have these characteristics include:

- 1 oceanographic survey vessels;
- . deep sea fishing vessels;
- 1 chemical, LNG, LPG carriers; and
- . passenger liners and ferries.

The arrangement of these vessels and comparable naval vessels should reflect a consistent approach by a shipyard to the use of an assembly strategy that is a consistent application of PWBS and GT principles.

There are a few features associated with the construction of naval vessels that cause some operational difficulties. These are the extensive operational and other documentation and the large number of engineering change orders that arise from requests from the Navy and from problems with government furnished equipment.

One possibility is to build merchant and naval vessels on adjacent, but operationally independent sites. A second possibility is for the government to significantly revise its behavior as a customer to shipyards building both Navy and merchant ships.

Whatever strategic approach is adopted, great care is required to ensure that a shipyard's ability to compete effectively with those shipyards that concentrate on specific markets for merchant ships is not undermined.

### **ADDITIONAL AREAS FOR IMPROVEMENT**

A second level of areas for improvement were also identified. These are considered to be important, but not as critical as the items described above. This second level list includes:

- . build strategy use;
- 1 steel stockyard, reduction in stock levels;
- 1 treatment line, use of weld through primers;
- . plate burning and marking, use of shrinkage allowances;



- <sup>1</sup> forming, use of line heating and nc machines (especially for stiffeners);
- <sup>1</sup> sub-assembly, work performed in defined Workstation,
- <sup>1</sup> flat panel assembly, updating of panel lines, use of more automation and elimination of welded fairing aids;
- <sup>1</sup> curved unit assembly, use of one sided welding and improved distortion control;
- \* block assembly, produce larger, more fully outfitted blocks and employ ground level transport systems;
- <sup>1</sup> staging and access, dramatically reduce staging requirements;
- <sup>1</sup> organization of work improve trade flexibility and provide area rather than trade supervision and
- <sup>1</sup> production control, reduce and level work package size and develop real time feedback and control systems.

## CONCLUSION

This paper is intended to provide information to U.S. shipyards as they **seek** to become commercially competitive. To some degree, the fact that U.S. yards have lost ground compared to their foreign competitors since 1980 **is** cause for concern. Without commenting on the reasons for this situation, the need to improve should be very clear.

There are some reasons for optimism contained in the results. Labor costs and average hours worked for U.S. yards are world competitive. Additionally, technology improvements needed are generally of the soft or management technology type, rather than facility or hardware type. Thus, major capital improvements are not required to produce major productivity improvements.

It is hoped that the recommendations will provide a framework for U.S. shipyards to conduct internal evaluations to set a course for international commercial competitiveness. These plans must be prepared and implemented in order to enable the industry to survive in the coming decade.

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## Technology Development: A European Experience

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### ABSTRACT

Since January 1993, the Estaleiros Navais de Viana do Castelo (ENVC) shipyard in Portugal has been engaged in a program of productivity improvement. In many other shipyards, the traditional approach has been to select wide ranging technology projects and to employ large teams of advisors and countermanagers. The approach here has been to involve key functional areas with wide involvement of yard personnel in driving the program forward. The consultancy team has been small and has acted as a catalyst and advisor on the management of change and the specification and implementation of new technology.

The central theme has been the establishment of workstation operations. The emphasis of the project has been in developing a structured approach to productivity improvement through the implementation of "best practice". The objective has not been to implement perceived latest technology, but to adapt the approach to suit local conditions and culture.

To date the results have been dramatic and far reaching. The yard is now adopting a radically new approach to planning and production engineering, to the preparation of production information and to the organization of work on the shop floor.

### BACKGROUND

Productivity improvement is a key issue facing the European Community (EC) shipbuilding industry and it will increasingly be so as subsidies are reduced and eliminated under the recent OECD (Organisation for Economic Cooperation and Development) agreement. While there are differences in productivity levels between Community and "best yards" elsewhere, there are also significant differences between the best and worst within the Community. Major improvements in productivity are possible now in most European yards through the adoption of modern shipbuilding techniques in terms of better systems and organization of work,

better production engineering, better management and better training.

The policy of the European Commission (the policy-making body of the European Community) towards shipbuilding includes in its objectives

- the promotion of a competitive shipbuilding industry seen as of vital interest to the Community and contributing to its economic and social development; and
- increased efficiency in European Yards.

In January 1992, as part of its continuing monitoring program of developments within the industry and progress towards the achievement of its objectives, the Commission appointed KPMG Peat Marwick in association with First Marine International to carry out a study to assess the factors which affect the competitiveness of the Community yards and to propose ways and means to enhance it. The study was completed in October 1992.

The ENVC yard was part of this study - it was one of the forty-eight yards visited and studied -- and the story begins here. Some additional information is given in the Appendix on the assessment of the use of technology in the shipyards visited at the time and what, broadly, was considered to be best practice. One thing that the study clearly showed was the correlation between the use of best practice, productivity and profitability.

The yard did not show well in the study (see Figure 1). In terms of productivity and in use of "best practice", it was well below average in its category. As a direct result of the findings, the consultants were invited to return to the yard for further investigations, and to design and implement a program for improvement. The object set was to draw up plans for productivity improvement in the widest sense - not just of the direct workforce - but of the whole organization and its activities.

The motivation for the improvement program was clear. The shipyard was government-owned and losing money. Money could continue to be lost at the yard but not for long. The tightening environment of EC

subsidy policy was expected to be increasingly felt.

Added to this was a strong political will for the yard's survival since it was, and still is, a major employer in the northern region of Portugal. Thus there was a strong commitment at the highest level to improve the performance of the yard.

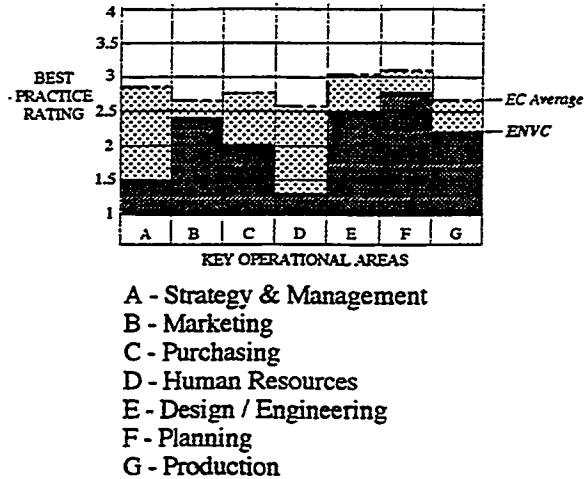


Figure 1  
Shipyard Use of Best Practice

## THE SHIPYARD

The shipyard is located on a 95 acre site close to the port of Viana do Castelo in northern Portugal. It employs a total of approximately 1,400 people in shipbuilding and ship repair.

Shipbuilding is carried out in a building dock and vessels up to 30,000 dwt. can be constructed. Blocks of up to 140 tonnes can be erected. The shipyard is well equipped with a good range of supporting workshops and other facilities. It carries out ship repair in two graving docks up to 30,000 dwt. (see Figure 2).

## BASELINE REVIEW

In January 1993, a detailed review of all shipyard operations was carried out. The objective was to obtain an up-to-date picture of the yard in an international context in terms of competitiveness, level of technology and productivity. It was to identify problem areas, to establish what could be improved, to propose how to manage change and to propose when and what new technology and new ways of working should be introduced.

The review involved interviews with department and section managers, study of systems and procedures,

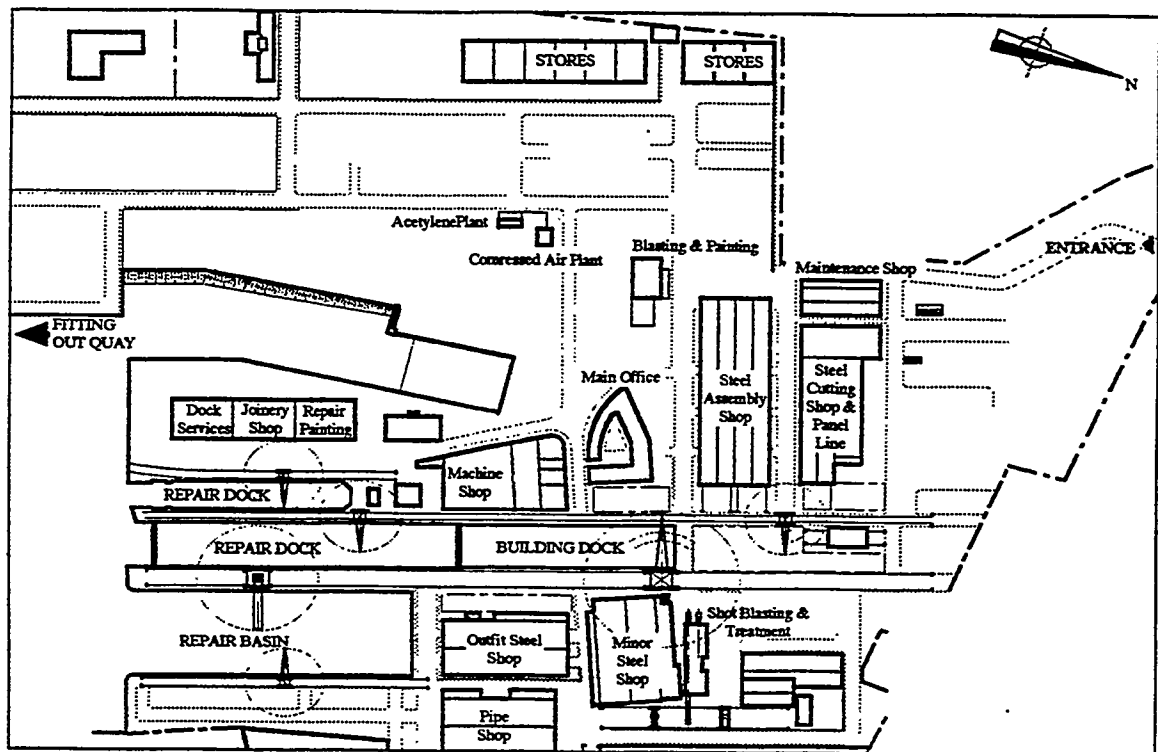


Figure 2  
Layout of Shipyard

examination of engineering documentation and production information, critique of the facility development plans and study of working practices. The findings showed nine common features which were identified from the studies in each department, summarized below.

### Non Quality Organization

There was a low level of commitment to a “right first time” philosophy with appropriate self checking and feed back systems. This showed in the repeated need for modification and rectification work

### Excessive Movement

This related to both manpower and materials and was primarily due to the absence of workstation concepts with proper planning and control systems.

### High Work in Progress

Stocks of raw materials and work in progress were appreciably higher than in comparable yards.

### Barriers to Change

The organization was heavily oriented towards departments and trades with poor communication between them and with significant barriers to cooperation and change.

### Low Customer Orientation

This applied both to external customers and to the adoption of the concept of “supplier / receiver” in internal workflows. This was reflected in the lack of inter-departmental communication, the repeating of the same errors, and the build up of frustration and inter-departmental friction.

### Low Awareness of Work Content

Monitoring and control were ineffective in production. Work was planned by large department / section manhour budgets split between shop and ship only. There were significant difficulties in reconciling estimated material and work content with materials consumed and manhours used.

### Global Control

At a high level, the company had relatively sophisticated controls. However, performance

measurement methods at sub-department and production levels were very under-developed.

### Low Organizational Learning

There were few systems for organizing feedback of actual performance or out-turn of activities.

### Shipbuilding Technology

In terms of shipbuilding technology, findings included the following.

planning dates were often missed, and poor quality and incomplete work was often passed to the next stage,  
there was poor dimensional quality, leading to excessive rework;  
there was no clear definition of stages of production and virtually no workstation organization,  
outfitting was generally carried out too late in the build cycle and was compressed due to late Steelwork activities,  
there was strong trade demarcation, little flexibility and evidence of overmanning; and  
the engineering offices were not oriented to steel / outfit integration or ease of production.

In time all these issues would have to be addressed. However, it was clear that it would be very difficult, if not counter productive, to try to address all the issues simultaneously. A phased program had to be developed.

### PHASED IMPROVEMENT PROGRAM

The program had to achieve three fundamental objectives

- the introduction of new shipbuilding technology and working practices,
- the break-down of the inter-departmental barriers, and
- progressive development of workforce involvement and commitment to the program.

It was decided to construct a three phase program as follows.

#### Phase 1 - Proving the Concept

This would consist of a number of relatively short term pilot projects aimed at “burning platform” issues in key activities, and involving a wide cross section of the management and workforce.

## Phase 2 - Developing the Skills

This would include a series of training and methods / procedures development projects involving transfer of technology which would develop the required approach and skills to enable the concepts demonstrated in the pilot projects to become "the way of life".

## Phase 3 - Making it Happen

This would aim to achieve full implementation of the new technology and ways of working into the day to day operations of the shipyard.

The projects were designed to implement change on specific contracts in the building program. The phases were structured to be self contained with definite cut-off points so that at regular intervals, progress could be reviewed and the future program modified as necessary. In addition, the shipyard could decide what level of external assistance (if any) was appropriate for the next stage.

The elapsed time for completion of the total program involving external consultants was expected to be two to three years. Thereafter, the improvement process was expected to be continuous and self generating.

## MANAGEMENT OF THE PROGRAM

Critical to the success of any improvement program is the project management organization which must be set up to manage the change process. Immediately following approval of the phased program, a management of change organization was established as outlined in Figure 3.

The Executive Committee was to meet about once a month and was responsible for:

- demonstrating senior management's commitment to and overall sponsorship of the whole program,
- agreeing on individual projects and resources in each phase of the program,
- monitoring progress and achievements, and
- resolving blockages and problems.

Project Steering Groups were established for each project. They were to meet every two to three weeks with responsibility for:

- ensuring the projects proceeded according to the program,
- ensuring the required results were achieved, and
- implementing changes resulting from the projects into their respective departments.

Project Action Teams were led by the project manager. Each action team was made up of staff and

workforce from the departments affected by the project and had responsibility for:

- developing and carrying out the project,
- developing the required technology, methods and procedures,
- highlighting problem areas,
- documenting the results and benefits achieved,
- assisting with implementation in their respective departments, and
- assisting with training their own and other department personnel.

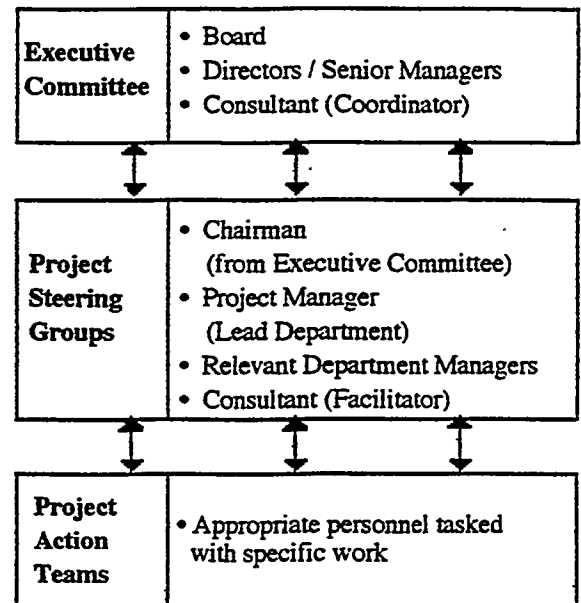


Figure 3  
Project Management Organization

The external consultants supported the steering groups and action teams in all aspects of their work, particularly in terms of technical advice. Up to four consultants were on site at any one time but with only a maximum of two for continuous periods.

## PHASE 1 - PROVING THE CONCEPT

Five key short-term projects were chosen to act as the initial focus for improvement (see Figure 4). Three were ship related and were designed to be in areas where rapid improvement was possible. They also involved a cross section of both technical and production departments and provided the basis for introducing management of change techniques to key people. Of the other two projects, one addressed the essential area

of human resources, the other looked for short term improvements in general steelwork production operations.

The ship related projects were aimed at impacting two sister ships in the building program to demonstrate the practical effects of new production technology in the areas of steelwork assembly and block outfitting.

ship Related	<ul style="list-style-type: none"> <li>1 Build Strategy</li> <li>* Steelwork Production</li> <li>1 Advanced Outfitting</li> </ul>
Human Resources	<ul style="list-style-type: none"> <li>1 Attitude Survey</li> </ul>
Short Term	<ul style="list-style-type: none"> <li>1 General Steelwork</li> </ul>

Figure 4  
Initial Projects

### Build Strategy

The main object of the build strategy project was to formally agree and document the construction methodology to be adopted for the two ships. This included the identification of potential problem areas and aspects of the vessels which were unusual, together with a description of how the problems would be overcome. In addition, the build strategy described improvements in technology and methods between the first and second vessels, and demonstrated the use of the document as a means of managing change. The project emphasized the need for team work and successfully brought together people from the principal departments of the shipyard.

It was agreed to appoint a project manager for the vessels whose principal task was to implement the build strategy. However, in actual practice, the strategy was not properly followed and the role of the project manager was reduced to that of technical coordinator. The main reason for this failure was the strong departmental characteristics of the company and an underlying resistance to change which was not overcome at this time.

It was not until the third phase of the program that the value of the build strategy and the role of the project manager was properly understood and appreciated.

### Steelwork Production

The main object of the steelwork production project was to demonstrate the principles and effects of the workstation concept on engineering and production activities.

Two steel blocks from the subject vessels were selected for the study. The project action team was responsible for:

- developing and documenting the detailed assembly methods and the required production information,
- specifying the necessary equipment, tools and manning levels,
- organizing and training selected production workers, setting up areas within the workshops to simulate workstations,
- overseeing the project through the production processes, and
- documenting results.

The project highlighted the changes in the approach to design and development of production information and in the organization and control of manpower and materials required to implement workstation operations.

The concepts of process analysis and workstation drawing were successfully introduced. In production, the project was initially successful but began to deteriorate as the workforce was changed without adequate training and the work areas were changed without adequate setting up. However, the workstation approach was appreciated by the production workers and supervisors and was adopted for other steel blocks not included in the pilot project. Figures 5 and 6 show samples of block process analysis and workstation drawings.

### Advanced Outfitting

The main object of the advanced outfitting project was to demonstrate the principles and effects of new outfitting technology in terms of outfit unit assembly and high levels of pre-erection outfitting in steel blocks (see Figures 7 and 8).

Two sets of system equipment were selected to demonstrate outfit unit assembly and two steel blocks - a funnel and casing, and an upper fore - end were selected to demonstrate the high levels of outfitting that could be achieved. The project action team was responsible for designing the outfit units, determining the levels of advanced outfitting, preparing the necessary production information and planning and organizing the production resources and materials.

The project emphasized the necessity to integrate steel and outfitting activities, both during the design and production stages. It also highlighted the need for a

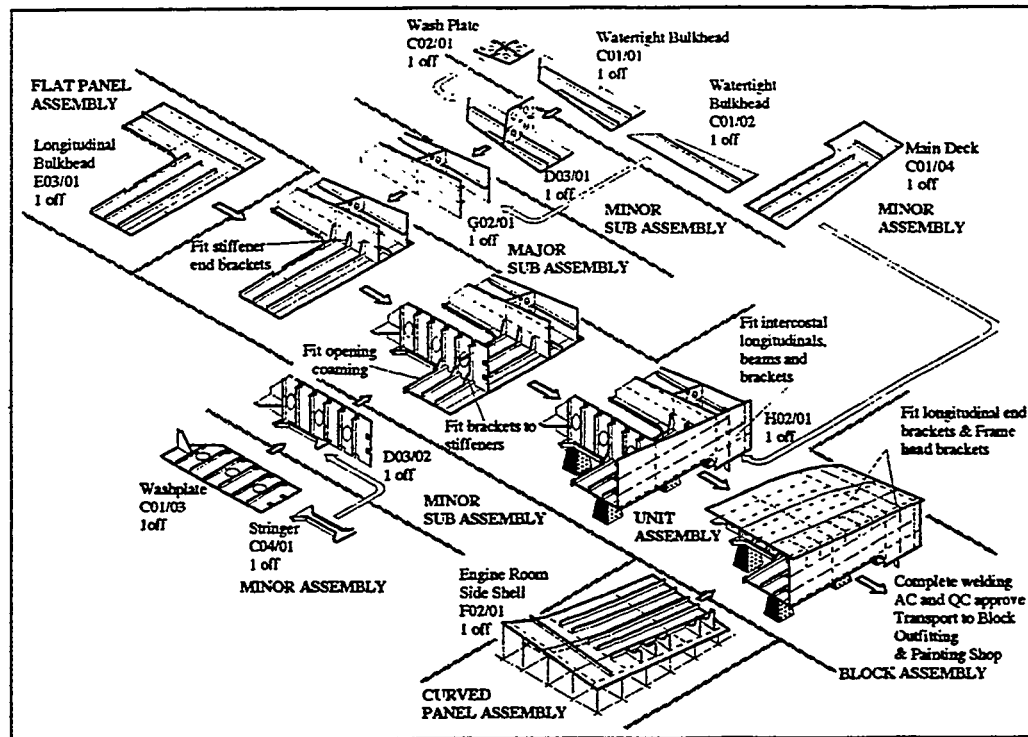


Figure 5  
Block Process Analysis

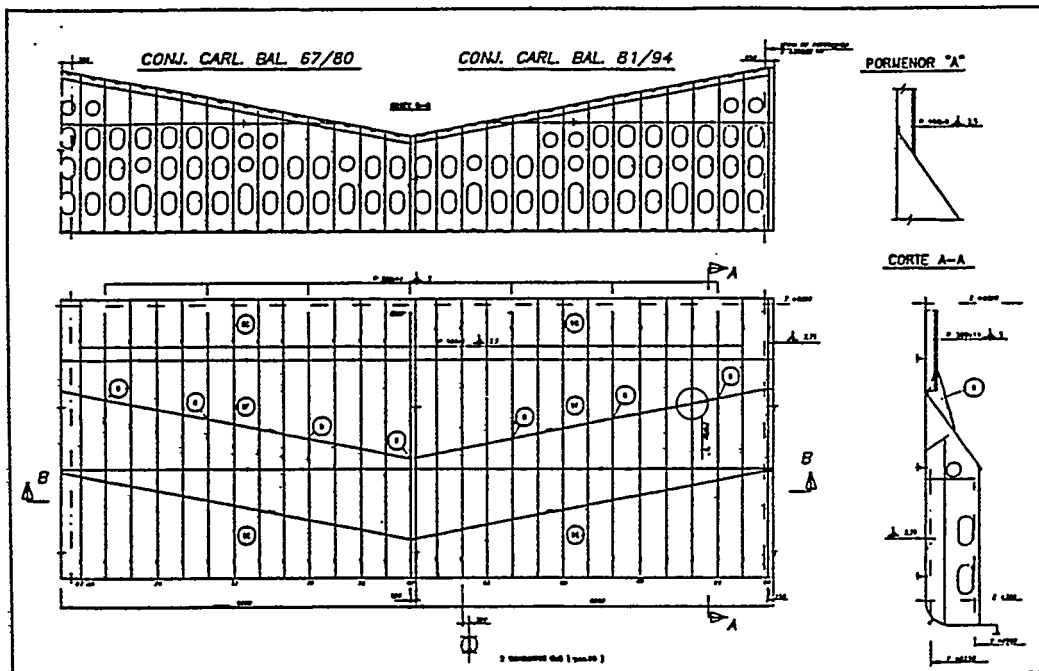


Figure 6  
Steel Assembly Workstation Drawing

new approach to the development of outfit design and of the format and content of production information.

In the first of the two vessels, only one of the two outfit units was successfully installed. Both were properly installed on the second. On the two selected steel blocks, a level of approximately 85% of targeted pre-outfit was achieved on the first vessel with 100% achieved on the second.

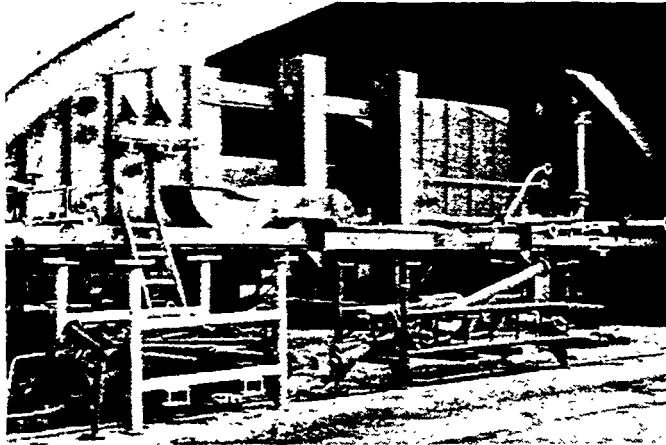


Figure 7  
Advanced Outfitting of an Engine Room Deckhead

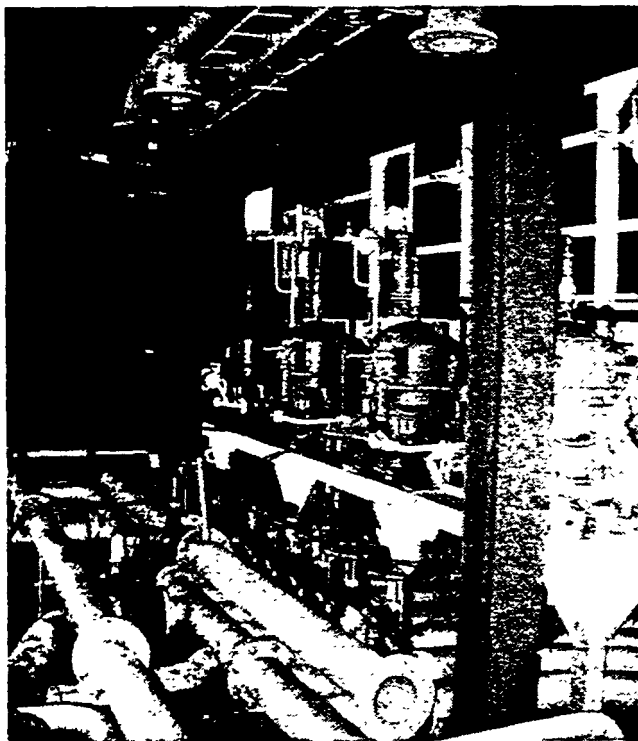


Figure 8  
Outfit Unit Installed On-block before Erection

## Attitude Survey

The main object of the attitude survey was to develop a better understanding of the different cultures and methods of working which existed in the yard and to develop a series of action plans to gain the commitment of the whole workforce to the improvement process.

The emphasis of the project was to highlight the human barriers which would hinder the progress and implementation of change and to develop the means of overcoming them. An anonymous questionnaire, which all employees were asked to complete, evaluated ten dimensions of human attitude in the company:

- management style,
- clarity of objectives,
- organizational integration,
- decision making,
- performance orientation,
- dynamism,
- professional development,
- image of the organization,
- motivation, and
- change.

The level of response was good, nearly sixty percent of the staff and workforce completed the questionnaire. Answers in each section were rated between 1 and 5 with 5 being the most positive attitude. The survey showed a great variation in attitudes between departments and levels within the organizational structure.

The company was found to be particularly weak in the areas of organizational integration (the extent to which the company achieves efficient communication and cooperation between the different units in the organization), management style (the level of encouragement and support to individual initiative when directed toward an improvement in organizational efficiency) and professional development (the extent to which the company provides opportunities for career development when preparing people for higher level positions). While there was a general willingness to change, this was being prevented by the weaknesses.

## Steelwork Operations

The object of the steelwork operations project was to design and manufacture jigs, small tools and fairing aids which could be used immediately in production to improve accuracy, shorten process times and reduce manhours in steel assembly.

The project emphasized the layout and operational changes necessary to implement workstation organization and the need for a structured, analytical approach. This project was a success and implemented



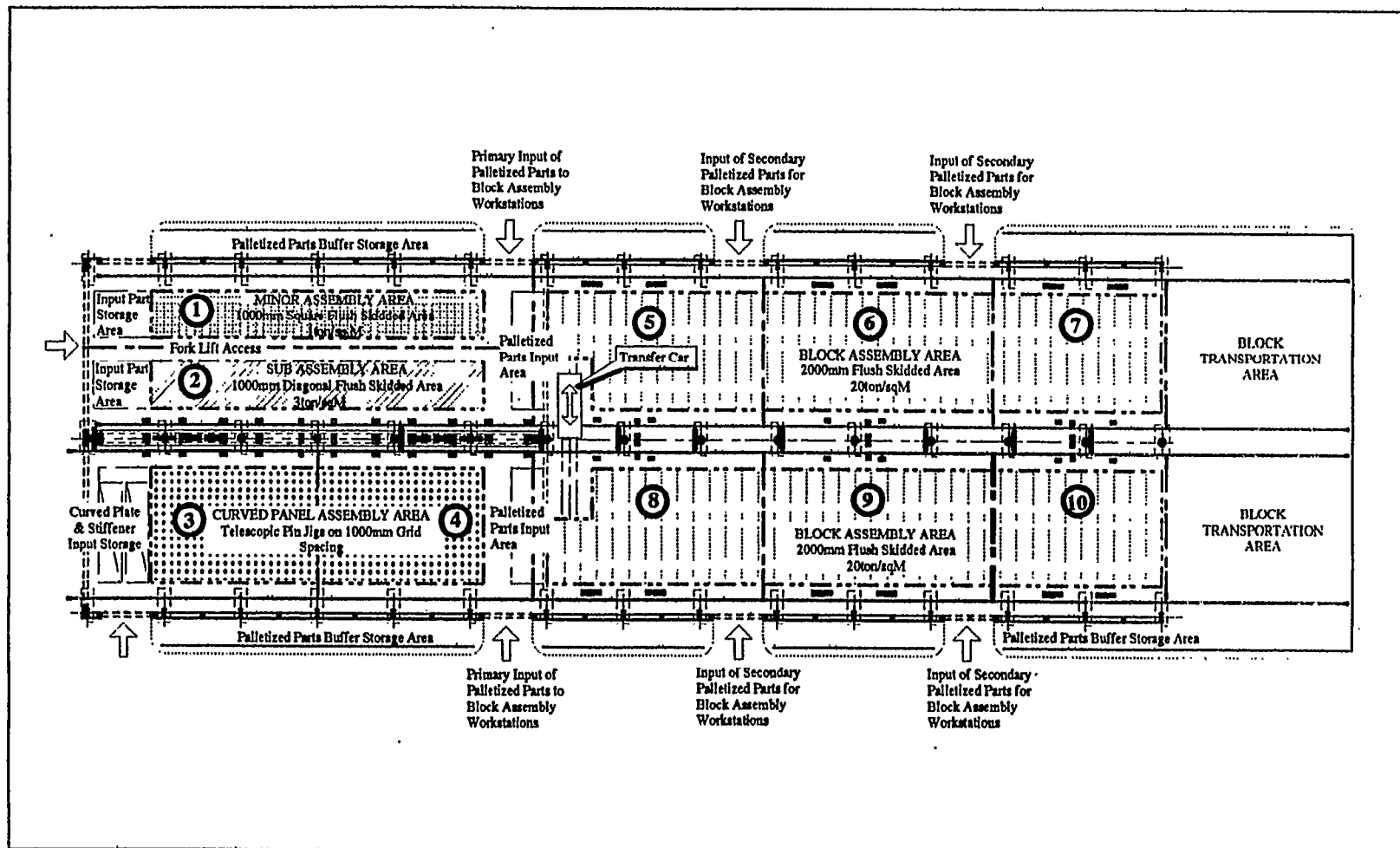


Figure 9  
Layout of Steel Assembly Workstations

many beneficial aids to production. Figure 9 shows the layout of workstations in the steel assembly area. Figure 10 shows pin jigs which were designed and manufactured in the yard and Figure 11 shows a number of small production tools and fairing aids

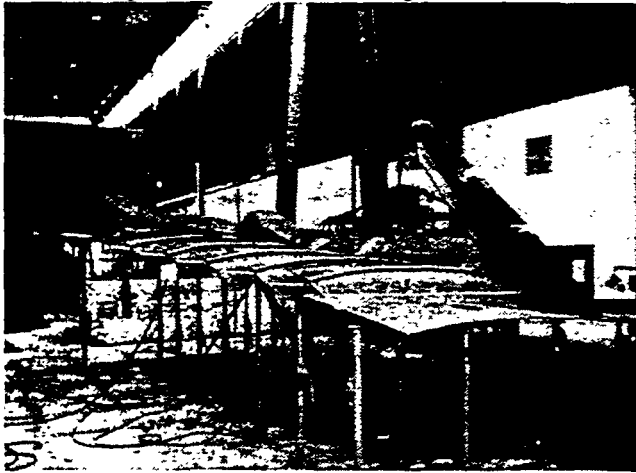


Figure 10  
Telescopic Pin Jigs in a Curved Panel Workstation

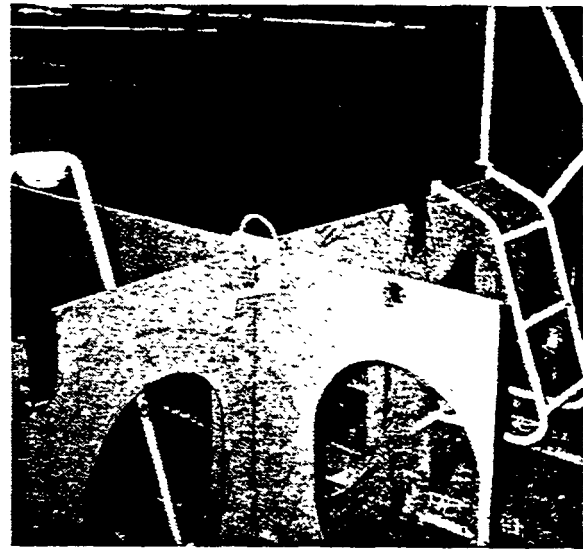


Figure 11  
Small Reduction Tools and Fairing Aids

## REVIEW OF PHASE 1

Following the completion of the Phase 1 pilot projects a formal review was carried out. This review highlighted a number of problem areas affecting the development and implementation of new technology. The purpose of the review was to help define the precise requirements and shape of Phase 2. The main findings are listed.

**Workstation Philosophy.** There were widely differing understandings of the workstation concept and the implications for the key departments. For successful implementation there had to be a common understanding throughout the company.

**Design / Production Information.** The traditional approach to the development of vessel design and the format and content of production information would not support and sustain workstation based production operations and zone by stage outfitting. A new approach needed to be developed.

**Planning System.** The existing planning system needed overhauling to be effective at all levels and, in particular, to control workstation operations through defined small work packages.

**Accuracy Control.** An accuracy control program was needed to define and achieve the accuracy requirements for each workstation.

**Workstation Operations.** The product types, operations, equipment, tooling and manning levels in each workstation needed to be clearly defined.

**Management of Change.** Broad based training at all levels was required to equip employees and managers with the techniques necessary to implement change.

**Professional Development.** The process of performance appraisal had to be improved by:

- face to face interviews on a regular basis,
- the setting of clear objectives, communication to individuals (or teams) of their performance against objectives, and the design of a fair and defensible promotion system.

**Organizational Integration and**

**Management Style.** There was the need for a clear definition of the management competencies and style of organization needed to achieve the business strategy. Also, a training program was needed for senior and middle managers to improve team work, communication, decision making and interpersonal skills.

## PHASE 2 - DEVELOPING THE SKILLS

Following the review of Phase 1, it was decided by the board that the emphasis of Phase 2 should be in the following four key areas:

- workstation operations training,
- development of the vessel design process,
- development of senior and middle management skills, and

development of workstation operations in steel assembly.

Figure 12 shows the key areas where the development of skills was required.

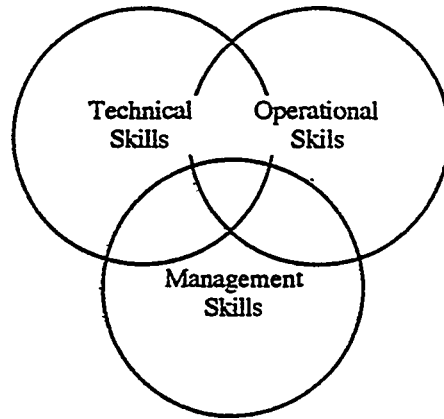


Figure 12  
Key Areas for Skill Development

It was decided that the problem areas of planning and accuracy control would be addressed in later phases.

For Phase 2 the executive committee maintained its mode of operation. The steering groups were reconstructed according to the four projects. Each of the action teams formed for the Phase 2 projects included at least one member from Phase 1. In addition, a technology manager was appointed to assume an overall coordination role and, with the assistance of the consultants, to develop an overall technology plan.

#### Workstation Operations Training

The main object was to achieve a broad understanding of the philosophy, benefits and implications of workstation operations. The action team developed extensive training programs at three levels:

- general instruction for directors and senior management,
- general instruction for middle management, and detail training for production management.

Members of the action team conducted the training sessions which were arranged for groups of six to ten persons. The emphasis of the project was on group participation through open discussion and the setting of tasks for the participants aimed at developing their

understanding of the concept and details of workstation operations.

#### Design and Production Information

The action team produced a “design strategy” document which described the approach to developing design and production information for a vessel through the major stages of the design process. Each stage was described in terms of functional requirements and production considerations and included decision making criteria and samples of the format and content of drawings and documentation. The project emphasized the need for integrating the steelwork and outfit design from the earliest stage.

The strategy document was designed to act as a guide for the engineering departments during the implementation phase. It was to be a dynamic document which could be updated as technology developments called for changes to the design process and the format of production information. Figure 13 shows a summary of the design strategy.

#### Management Skills Training

The object was to develop modern management style and skills in senior and middle level managers, promoting interdepartmental communication and cooperation for mutual benefit. Training seminars were held for managers at different levels in the organizational structure. Following training seminars, the managers were divided into small groups and given various problems to solve which required joint solutions. The project emphasized the need for close cooperation between managers while providing new techniques and approaches to problem solving.

#### Workstation Operations

During Phase 1, the layout of the workstations for steel assembly were designed and agreed. The object of Phase 2 was to define the detailed operations and to start implementation.

Previous vessels were analyzed to establish the product families and the throughput requirement for each workstation. Methods and procedures for assembling each product were developed and described in an operations document. Manning levels were determined for each workstation based upon the throughput and methods to be applied.

The project successfully started the implementation of steel assembly workstation operations. The same principles were used to define workstation operations for outfit production, beginning with pipework and

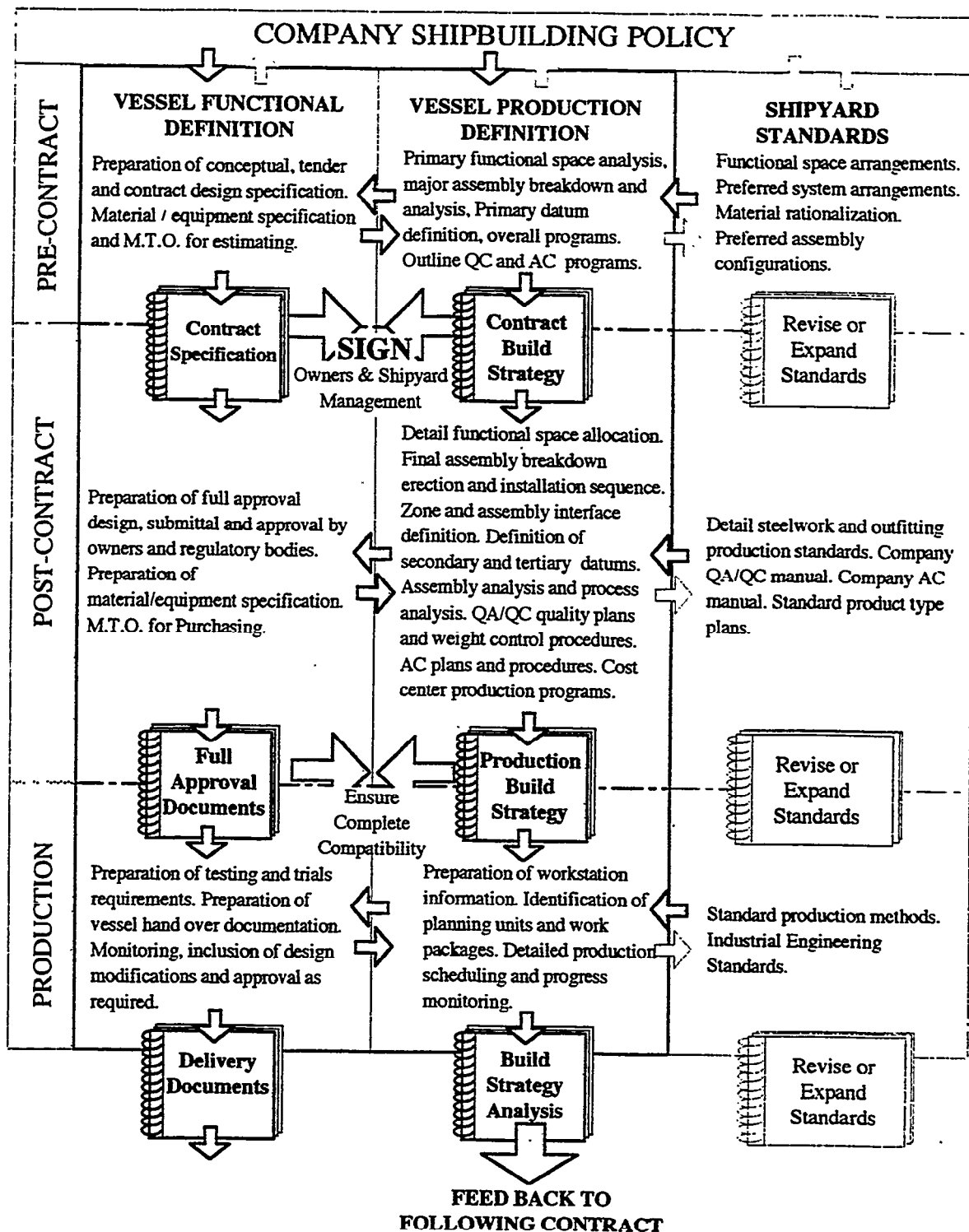


Figure 13  
Outline of Ship Design Strategy

progressively moving to other activities. Figure 14 show's the initial stages of developing the minor assembly workstations.

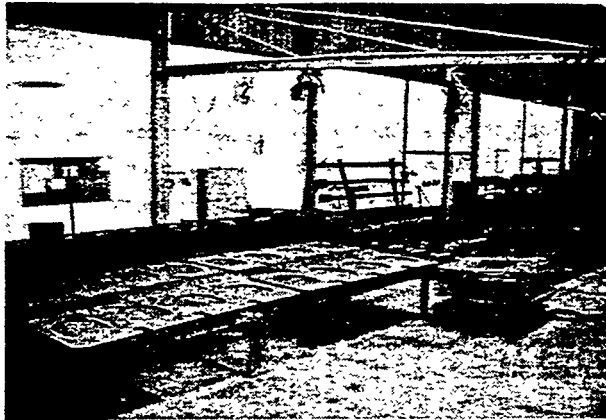


Figure 14  
Start of Minor Assembly Workstations

## REVIEW OF PHASE 2

By the time the four projects in Phase 2 were complete, the improvement program had been running for approximately twelve months. While they had been generally successful, with many new methods and procedures implemented, it was felt that the individual project approach needed to be expanded to a full implementation program.

With the development of the new "design strategy" and the eroding of departmental barriers, the major obstacles to change were being overcome. However, training needed to be extended, the planning problem remained to be addressed and, in addition, two organizational problems needed to be solved, as described below. Figure 15 illustrates the key areas for further development in Phase 3.

**Management Skills Training.** Phase 2 focused on basic management skills training for senior and middle managers. This training needed to be expanded to other levels of management and supervision.

**Workstation Operations Training.** The training needed to be extended to provide detail training for engineering personnel and workstation supervisors.

**Planning System.** The existing planning system needed to be restructured into a decentralized, three tier system for the effective planning and control of workstation operations.

**Production Engineering.** There was a need to

establish a production engineering function which would lead the build strategy preparation for each vessel and would ensure that new methods and procedures adopted by all departments were adhered to and coordinated. The production engineering function would also be responsible for leading the continuing technology development effort.

**Engineering Departments.** The traditional steel and outfit department organization was still in place and needed to be changed to multi-disciplined sections developing integrated design and production information.

Extension of Training	. Management Skills . Workstation Operations
Planning	. New System
Solution to Organizational Problems	1 Production Engineering 1 Engineering Departments

Figure 15  
Needs for Phase 3

## PHASE 3 - MAKING IT HAPPEN

In late 1993, the yard won an order for the design and construction of an 8,700 dwt. cement carrier. Following the review of Phase 2 in January 1994, the board decided to commit the company to the full implementation of new technology on this vessel. Phase 3 of the program started in earnest in April 1994 and is planned to extend to July 1995 at which time the vessel will be ready for delivery.

Methods and procedures developed in the previous phases are being applied to the vessel, starting with the production engineering of the basic design, preparation of assembly analysis and preparation of workstation production information.

In addition, the following projects identified in the review of Phase 2 are being carried out.

### Workstation Training

Detailed training programs are being written for workstation supervisors and for staff from the engineering, planning and production engineering departments. Applying the methods developed for the

previous training programs using the subject vessel as the basis, attention is being focused on training for workstation operations in both steelworking and outfitting.

### Workstation Operations

Implementation of steel assembly workstations is well advanced (Figure 16 shows a bilge sub assembly being completed at a sub assembly workstation). The stages of assembly are clearly delineated in the workshops with appropriate floor skids, jigs and supports, equipment and crange, access-ways and intermediate storage areas. Implementation is being extended to outfit production activities in preparation for the start of production of the cement carrier.



Figure 16  
Sub Assembly Workstation

### Planning System

The existing planning system has been reviewed and new methods and procedures are being written to describe the detailed operations of a decentralized planning function at three levels:

- strategic planning,
- tactical planning, and
- detail production planning and scheduling.

The new system is being implemented progressively during the design and construction of the vessel. Figure 17 shows the basic principles of the planning system.

### Production Engineering

Organizational and personnel problems made it very difficult for the company to establish a production engineering department at the beginning of Phase 3. However, a planning and production engineering

department manager has now been appointed to manage the planning and production engineering tasks which are partly carried out by his own staff and partly carried out by personnel in other departments. While this is not an ideal situation, it is a satisfactory, temporary measure which enables the production engineering principles, developed in the design strategy to be incorporated into the vessel.

In engineering, planning and production areas, the inter-departmental barriers are not totally dissolved and applying certain fundamental production engineering principles is difficult. One typical area involves the block breakdown in the engine room where there has been insufficient consideration of the best breakdown to suit important outfitting requirements.

Figure 18 shows the shell seam at the engine room tank top level whereas it should ideally have been located above the engine room floor plate level. This would have increased the level of advanced outfitting and open-sky access.

### Engineering Departments

In the period between the completion of Phase 2 and the start of Phase 3, the company was unable to achieve full integration and reorganization of the steel and outfit engineering departments. A partial reorganization of staff on a ship primary zone basis was achieved and the departments are applying the new methods and procedures set out in the design strategy. This is significantly changing the approach to the detail design of the vessel and the format and content of production information. Workstation drawings are being produced for the steelwork assembly stages and outfitting information is being prepared by zone and stage.

### Management Skills Training

The basic management skills training in Phase 2 was conducted entirely by the consultants. In Phase 3, the training sessions are being conducted jointly by consultants and yard staff. The training program is planned to extend from September 1994 to February 1995. It will cover all levels of management and will address the following area:

- strategic management,
- organizational behaviour,
- personnel management,
- time management,
- production management,
- resource administration, command and motivation,
- production results control, and
- leadership.

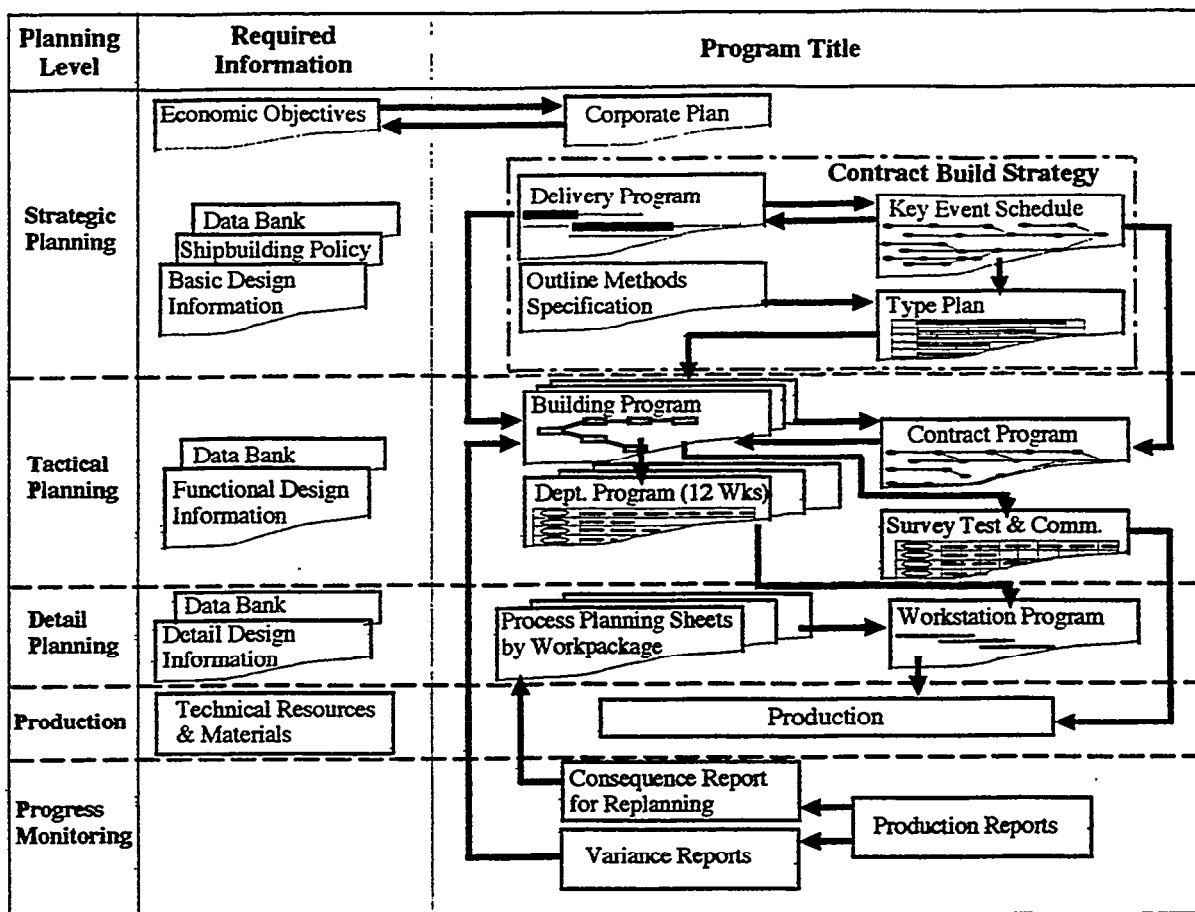


Figure 17  
Principles of the Planning System



Figure 18  
Shell Seam at Tank Top Level

## KEYS TO SUCCESS

While the principles of best practice shipbuilding technology are applicable to all shipyards, their interpretation and incorporation into a structured productivity improvement program must be carefully considered on a yard by yard basis. In this way the very different cultures, personalities, barriers to change and local conditions found in any given situation can be recognized and accommodated.

Throughout the program at the shipyard, much effort has gone into adapting the approach to performance improvement and technology development to suit local conditions and culture. The importance also of simultaneously addressing the elements of new technology and human resources has been stressed, as has the need to ensure that the applied technology is balanced across all shipbuilding activities.

In many shipyards the approach has been to select a

wide variety of projects and to employ large teams of advisors and counterpart managers. In this case the approach has focused on a limited number of projects which affect a wide range of activities and the consultancy team has been kept small. This was considered to give the best chance of success.

The principal role of the consultants has been to act as a catalyst for change by providing the ideas and stimulus through their knowledge of best practice shipbuilding technology and their experience in other shipyards and in other industries. They have acted as advisors on the management of change and have provided detailed, hands on, methods and strategies for the implementation of new technology and ways of working.

There have been compromises in areas where the consultants have wanted to move faster or do things in different ways; but where the shipyard, for its own good reasons, has decided otherwise. Mistakes have been made, of course, but some tolerance of failure is necessary for learning organizations and continuous improvement

The improvement program aimed to develop a wide management and workforce involvement and commitment. It was structured to involve a broad cross-section of yard people at all times, and encouragement was given to those involved in projects to develop their own solutions to help avoid the "not invented here" syndrome.

At predetermined intervals in the program, seminars have been held for key employees at which senior managers, supported by the consultants, have reviewed progress, highlighted the successes and failures, and described proposed future program activities. As the projects have progressed, problem areas and results have been presented and discussed with affected management and workforce. This policy of communication at all levels has been essential in gaining the confidence and commitment of the workforce.

In a number of areas, methods and practices from outside the shipbuilding industry have been introduced to avoid traditional incest and inbreeding. Key areas were those of attitude survey, personnel assessment, management organization and management skills training.

In shipbuilding technology, the emphasis has been carefully focused on developing:

- build strategies,
- design for production,
- workstation organization, and
- steel and outfit integration.

Success here has led directly to cycle time reduction and manhour and cost reduction.

In summary, the key factors for a successful

productivity improvement program include the following:

- not just commitment from the board and senior managers but their full involvement in project steering groups - this is not something that can be delegated,
- involvement and full communication with all employees,
- emphasis on the shipyard developing its own tailored solutions,
- consultants as trainers and mentors providing solutions as requested,
- parallel development of technology and human resources, and
- clear technological focus.

The object of this whole exercise was to improve competitiveness. In the 1992 EC study, competitiveness was defined as "the ability to win orders in open competition and stay in business". Improving productivity is a means to the end - not the end in itself.

Finally, it is pleasing to note that the yard's orderbook has improved dramatically in the last twelve months as can be seen from the building programs shown in Figures 19 and 20. Continuous improvement in performance is required to meet these new commitments. When this paper is presented it is hoped that further significant progress can be reported.

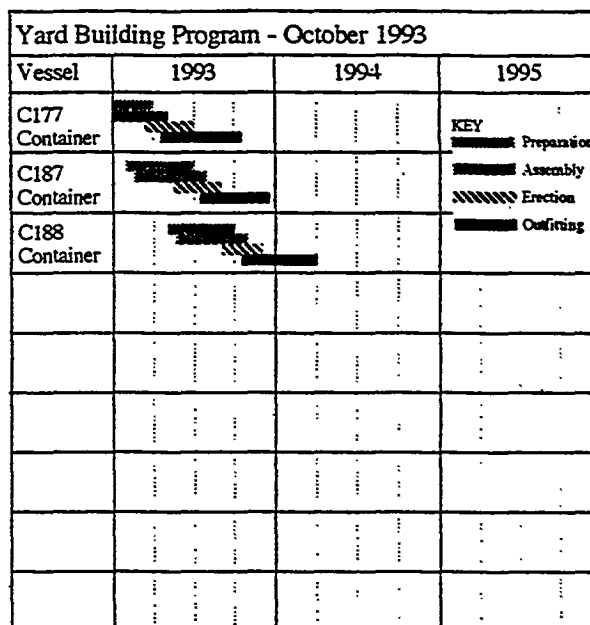


Figure 19  
Yard Building Program - October 1993



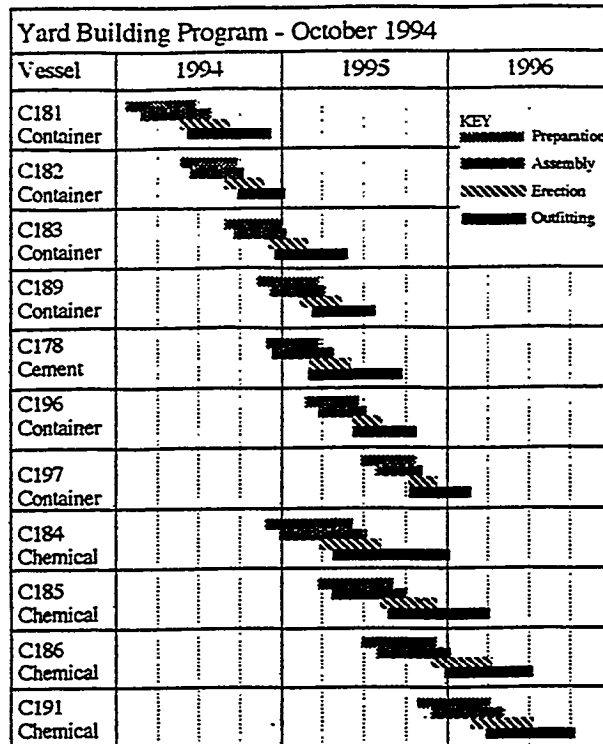


Figure 20  
Yard Building Program - October 1994

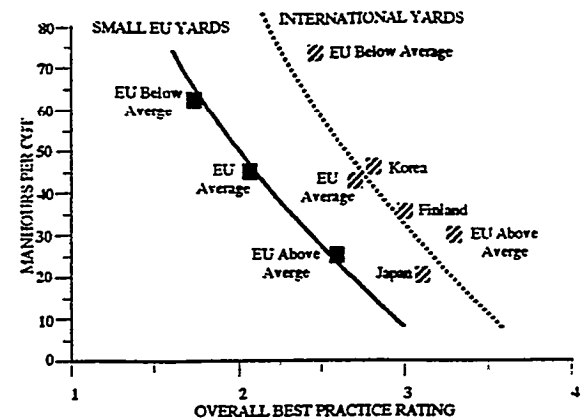


Figure A1  
Best Practice / Performance Correlation

	Best Practice Measure	Perform. Measure	Profit Measure
EC Above Av.	117	150	91
EC Av.	96	105	70
EC Below Av.	88	65	23

Table 1  
Best Practice / Performance / Profitability Correlation

## REFERENCES

KPMG Peat Marwick in association with First Marine International Ltd. "Report of a Study into the Competitiveness of European Community Shipyards" October 1992

## APPENDIX

The above referenced EC study proposed that each yard must maximize its use of resources by ensuring that it is using best practice as appropriate to its size, type and individual business objectives. The research program and analysis demonstrated the link between the use of best practice and output performance which is shown in Figure A1.

The study also showed a clear relationship between use of best practice, performance and profitability. Summarized as shown in Table 1.

There are significant differences in the adoption of best practice across EC yards. The features which typify the above average and below average performers in seven key areas of company activity are summarized below.

On strategy and management issues, the above average performing yards have a high degree of focus on a specific target market. This focus links through to clear management objectives and actions in each functional area. In contrast, the below average yards stress the need for flexibility and tend to be trying to service a number of different markets with a mix of one-off builds and short series. This leads to confusion in coordinating departmental organization structures and in the allocation of resources.

On marketing, the higher performing yards tend to have clearly identified and targeted owners, have a policy of pro-active contact with shipowners, see after-sales as another contract opportunity not just a cost, and use their own resources with minimum use of agents. The below average yards tend to be totally re-active to enquiries, view orders as one-offs rather than part of a long term relationship with shipowners, have no clear product development priorities and have very few resources in sales and marketing.

In purchasing, the above average yards tend to have reduced to only two or three suppliers in each area, to operate with few sourcing restrictions and to have explored economies of scale by linking purchasing with

other yards. The below average yards tend to operate within more constraints imposed by their lack of knowledge of external financing sources and to use traditional buyer/seller relationships.

In human resources, the major differences between above and below average yards are in four key areas:

- the emphasis on upgrading skills,
- the effort to restructure the workforce through recruitment,
- the degree of employee empowerment, and multi-skilling and re-skilling.

On design and technical issues, above average yards have invested heavily in CAD/CAM systems and equipment with careful implementation, the production of specific workstation information and increasingly full CAD/CAM generation of production information with DNC links. Some of the average and below average yards have made the investment but implementation has been ineffective and not integrated with other operations.

In planning for production, the high performing yards have decentralized multi-level planning systems with clearly defined outputs at each level, a work package approach to organization of work, formal build strategy documentation, computerized material control systems and pre-production marshaling of kits of parts. The below average yards are ineffective in these areas.

On production, above average yards have short build cycles to maximize the use of facilities. This is achieved by implementing workstation concepts with clearly defined process flows, superior build sequences and early outfitting techniques. There is a high priority on accuracy control and on both designing and organizing out needless work. Below average yards tend to use a more traditional sequential approach to ship construction.



**THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS**  
**601 PAVONIA AVENUE, JERSEY CITY, NJ 07306**

Paper presented at the 1995 Ship Production Symposium  
 Westin Hotel, Seattle, Washington, January 25-27, 1995

**Economics and Management of American Shipbuilding and the Potential for Commercial Competitiveness**  
 Ernst G. Frankel (LM), Massachusetts Institute of Technology, U.S.A.

**ABSTRACT**

Defense conversion and commercial shipbuilding competitiveness have become major goals of the government in maintaining the U.S. shipbuilding base. The government enacted the National Shipbuilding and Shipyard Conversion Act of 1993, established a National Shipbuilding Initiative, disbursed ARPA funds for various enhancement projects, and provided support to the industry through Maritech. Yet these initiatives may not help to revive the industry and reestablish it as world class.

The reasons for the lack of competitiveness and the effects of the proposed government measures are discussed in economic terms here. The differences between U.S. and foreign shipbuilding costs are analyzed in a rational manner without subterfuge under clouds of real or imagined protection or subsidies offered. The conclusions are that U.S. government involvement in encouragement or protection has a very high price and that the U.S. shipbuilding industry may have a better chance of survival and revival with less or no government aid, protection, and involvement.

**INTRODUCTION**

The U.S. was the world's foremost commercial shipbuilder fifty years ago and has since lost its ability to compete globally in shipbuilding. The initial decline in the post World War II period was the result of shipping overcapacity caused by left over World War II tonnage which in turn forced the shutdown of most U.S. shipbuilding capacity. The increasing inability of U.S. shipbuilders to compete and even maintain an effective commercial shipbuilding base in the U.S.

was largely caused by government aids, protection, and regulation as well as the virtual monopolizing of most major U.S. shipyards by a single client, the U.S. government.

It is a basic finding of economics (Thurow, 1992) that government subsidies, aids, protection, and regulation of an industry will cause its productivity to decline. Unless an industry is forced to compete in an open marketplace without aids, market protection, and price fixing, it will not and cannot attain effective productivity and thereby a competitive position. The industry is at a stage when government demand for U.S. shipbuilding output will continue to decline and probably level off to where it requires but a small fraction of the current, already largely depleted, U.S. shipbuilding capacity.

**SITUATION AUDIT**

The budget request for Navy construction for FY95 is only \$5.585 billion, and over the next five years, to the end of the century, Navy plans are just to build 15 DDG-51s, four LX amphibious ships, one MCM, and two TAGOS ships (Marine Log, 1994). This program will maintain a navy shipbuilding budget of barely \$5.00 billion per year. On the commercial side Title XI ship mortgage loan guarantees have been increased to \$1.5 billion for FY9-4/95 domestic shipbuilding (Marine Log, 1994). A large proportion of these funds have now been allocated but in a somewhat distorted manner with only a small percentage of these funds destined to the major U.S. yards which were to be saved from serious decline under the defense conversion policy.

Another relevant development is the proposed ten-year Maritime Security Program with a budget of \$1

billion under which operators of young (less than fifteen years old) military useful ships could obtain direct annual payments of \$2.5 million each for up to 32 cargo ships.

The government's shipbuilding program for conversion to competitive commercial ship construction includes ship construction loan guarantees to support sale of up to \$3 billion of ships built in American shipyards, in addition to the Maritech Program which is designed to promote technology transfer, process improvements, product development, and productivity/ quality enhancement in U.S. shipyards. Maritech is supposed to also provide for improvements in shipbuilding competitiveness by encouraging industry and government partnerships as well as mutual support arrangements.

As a result of the demise of the STP (Series Transition Payment) subsidies program of the Organization of Economic Cooperation and Development (OECD) agreement this only leaves two important federal shipbuilding programs in place, the revitalized Title XI Ship Mortgage Guarantee Program and the Maritech R&D Program. The objectives of Maritech are to develop new technologies and processes for the production of commercial ships including new commercially competitive designs and marketing approaches. While these may be important and may provide U.S. shipbuilding with new products and production processes, they will not in themselves make American shipbuilding more competitive. We do not need new product and process innovation but need to learn how to better use existing process technology to build current designs of advanced ships.

The private U.S. shipbuilding industry now employs about 65,000, a number still 20% higher than the number of workers employed by all the major Japanese shipbuilding firms (shipyards building vessels of more than 10,000 DWT) which produce close to 30% of world shipbuilding output (Japan Maritime Research Institute, 1994).

#### THE COMMERCIAL SHIPBUILDING MARKET

World ship orders have increased since 1991 and 1992 and reached over 18 million gross tons in 1993,

a volume which is expected to be exceeded in 1994 (Clarkson Research Studies, 1994). This trend will continue as a consequence of the rapidly rising increase in world ship scrapping which exceeded new orders in both 1992 and 1993, notwithstanding comparatively low scrap prices.

The decline of world newbuilding market share of Japan which dropped below 30% in the first nine months of 1993 is significant. European yards share on the other hand increased to over 20% during that period.

The tanker and bulker tonnage (dwt) delivered by the world shipbuilding industries is growing rapidly and reached 21.9 million dwt in 1994 and are expected to surpass 25.0 million dwt. These consist of

	<u>1993</u>	1994
Tankers	10.8 dwt	12.0 dwt
Bulkers	<u>11.1 dwt</u>	<u>13.0 dwt</u>
Total	21.9 dwt	25.0 dwt

Table I - Tanker and Bulker Construction

At the same time requirements for new tonnage has increased from a total of 485.8 million dwt in 1993 to 532.2 million dwt in 1994. This means that current shipbuilding demand is only 1/23.66 of the currently required tonnage. Similarly current supply of tonnage in 1994 was: tankers, 281.7 million dwt and bulkers, 236.5 million dwt; for a total of 528.2 million dwt, or about 7% above current (1994) required tonnage.

In other words, with an average life of tankers and bulkers now well below 20 years, particularly for very large vessels, this replacement rate is not only inadequate to maintain required fleet strength at the current average age of the fleet; but also does not satisfy the growth in demand for tonnage which is 3.0% per annum just in terms of ton-mile transport requirements. Adding the need for regulatory and technological upgrading of the fleet by substituting existing single hull with double hull tonnage, and intro-

duction of more efficient and automated vessels, adds at least another 6.6% of existing tonnage demand per year for a total newbuilding demand rate of 9.6% per year, well above the actual 4.51% rate in 1994, which was less than half the required rate of replacement (Clarkson Research studies, 1994).

Considering container ships, the situation is different. DWT on order increased from 2.5 million in 1990 and 1.9 million tons in 1991, to 2.9 million in 1992 and 4.0 million in 1993 (Clarkson Research Studies, 1994). Ships on order in 1994 are expected to reach 4.6 million dwt. This rate is equal to over 8.2% of existing fleet capacity which has an average age of less than 9.2 years (on a dwt basis) and is therefore well above replacement rate. The optimism by owners is largely based on an expected prospects of growing trade with China, Russia, Eastern Europe, and the rest of the Pacific/Far East.

Container shipping, though currently oversupplied with an excess in slot-mile capacity of over 35%, is expected to continue to generate a growth in demand of more than 11% per year in slot miles. The prospects for world shipbuilding are therefore quite bright, notwithstanding the fact that orders in some segments of the market actually declined in 1994.

In tankers, Suez Max and handy-sized tanker orders grew substantially in 1994, while among bulkers Cape size bulker orders grew marginally. All other tanker and bulker categories actually experienced significant falls in orders in 1994.

Container ship demand similarly dropped off marginally in 1994 when compared with 1993 orders, but are still well ahead of 1992 orders.

Overall demand for new vessels has shrunk somewhat in 1994, but the value of orders has remained remarkably steady as price increases made up for volume of orders.

The brightest segment in world shipbuilding remains the special vessel category such as chemical and LNG carriers, ferries, fast special craft, cruise vessels and various types of special support vessels.

While Japan, South Korea, and China still account for about 60% of the orderbook, European yards have

made a remarkable comeback and now supply nearly 20% of the world orderbook in millions of CGT. They account for over 36.9% of the world orderbook by value.

Many European and Japanese shipyards have become very productive in the last ten years and have more than doubled labor productivity during those last ten years, a trend which continues. This isolated them from the effects of the declining value of the dollar and other developments.

For example Odense now requires only 84% of the manhours of the best Japanese yards and 40% of those of a good Korean yard to build a large tanker (J. Anderson, 1993). U.S. shipyards not only have the potential of attracting foreign commercial orders with low cost Title XI financing, but have in addition the opportunity for replacing the 200-odd average tankers in the U.S. flag cabotage fleet. This alone is a market with a potential value of \$10.0 billion over the next 6-8 years which is roughly the period during which most of these vessels should be replaced.

Adding to this the prospects of 1-2 cruise ships, 3-6 container ships, and an array of other vessels per year, U.S. shipbuilding could easily establish a commercial market of \$3-4 billion per year, a volume which would be adequate to support U.S. commercial shipbuilding employing about 20-22,000 people. This is only about one-third of the current U.S. shipyard employment level. This business furthermore would only accrue to U.S. yards if:

1. U.S. shipbuilding productivity increased appreciably;
2. delivery times are reduced to a fraction of those currently required;
3. U.S. shipbuilding management is streamlined and the ratio of white collar to value collar workers is reduced from 1 to 3 to 1 to 7; and,
4. government gets out of regulating, subsidizing, or otherwise interfering with U.S. shipbuilding.

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Total cost of cabotage is about \$3.1 billion/year.

Yards must become innovative not just in product and process technology but in management and operations. The U.S. yards in general are not just obsolete in facility and process technology terms, but more importantly in terms of the way they are structured, organized, managed, marketed, and run.

The problem therefore is not just one of assuring a level playing field (often interpreted as eliminating subsidies offered to shipyards abroad) and providing government funding for product and process technology innovation, but one of restructuring the whole of the U.S. shipbuilding industry and most importantly most individual yards.

#### U.S. SHIPYARD LABOR PRODUCTIVITY

American shipyard workers are competent, creative, and mostly hardworking. This has been shown repeatedly from evaluations of individual shipyard worker output per unit time and in their approach to the solution of shipyard production problems. The problem is not with the workers, it is with the environment in which the worker performs. The principal factors influencing U.S. shipyard worker performance are follow.

##### Lack of Effective Ship Production Management

The lack of effective ship production management includes the following items: planning, supervision, inspection and physical facility/equipment provision. Management is often incompetent, inexperienced, or disorganized. As a result material and production process flows are not effectively coordinated. Tools, equipment, and material (raw material and material in process) are not delivered just in time to locations where they are required. The same applies to personnel. Inspection is often ill defined and not introduced in a continuous manner into the production or assembly flow. Similarly facilities are often not ready when and where required.

##### Lack of Worker and Manager Training

Training in shipbuilding as in all manufacturing must be a continu-

ous process where workers and managers regularly undergo training. While European and Far Eastern shipyards spend 1.0-1.5% of revenues on training (an average of 8.4 and 9.2 days per year) on full-time training of everyone, U.S. shipyards spend a dismal 0.25% or one-sixth as much and most of it is expended on marketing, lobbying, and other management type training. Practically none goes for worker skill training. This has slightly improved in recent years and in response to Total Quality Management (TQM) requirements. Yet even this type of training is often wasted as many of the trainees lack basic understanding of the elements of statistics which are essential for a proper application of TQM tools and methods.

##### Working Conditions

Working conditions are usually poor. Not only are facilities and ships often ill maintained and dirty, but workers and supervisors often dress in indescribably filthy and inappropriate clothing. This compared to company-provided white or other color coveralls in most foreign shipyards which not only improves worker morale but also work safety and self esteem. Similarly workers will treat equipment very much like the way they are treated.

##### Multi-tiered Hierarchical Line Organizations

Most American shipyards are organized as multi-tiered hierarchical line organizations with as many as 18 levels between worker and yard manager. Shipyards need to have flat free form flexible organizations with some matrix characteristics which empower workers at all levels and assure proper feedback and feed forward of information. Decision functions and responsibilities must be delegated to the lowest competent level. This assures not only better and more timely decisions but also assures proper sharing and transfer of information resulting from and required for such decisions.

##### Casual Labor

American shipyards are among the few who still maintain a casual

labor environment where people are hired and fired all the time, instead of being allowed to move from one department or job to another to safeguard use of the workers' skill as well as his or her loyalty.

Similarly financial incentives such as profit sharing, year-end bonuses, and general recognition of contributions made by individuals should be introduced. Workers should also be given opportunities to relate to the customer, learn about the expected use of the vessel and the conditions under which the ship is expected to be used. Workers must not only feel financial satisfaction but also pride of ownership, personnel recognition, and peer acceptance.

American shipyards have lots of catching up to do in these areas. Currently U.S. shipyard labor productivity is only one-third that of Japan as noted in Table I.

	EC	Japan	U.S.
Best	26	20	60
Average	44	23	82

Table I - Shipbuilding Productivity (MH/CGT) (J. Anderson, 1993)

The most productive of EC shipyards actually achieved just under 18 MH/CGT. The average and best productivities are in Japan. At this time some of the differences in labor productivity are absorbed by the differences in shipyard labor cost (Table II).

South Korea	0.64
U.S.	1.00
Denmark	1.33
Japan	1.35
Germany	1.36

Table II - Relative Shipyard Labor Rates - in 1993 U.S. Dollar Equivalents Costs (Including Overhead and Benefits)

The continued devaluation of the U.S. dollar since December 1993 has increased the gap in relative shipyard labor costs by over 18% and

therefore today Japanese and German shipyard labor costs are 52% and 54% higher than those in the U.S.

There are many reasons why U.S. yards did not achieve productivity gains, notwithstanding many years of research and development. The reasons are manifold and include:

1. ineffective shipyard organization and management;
2. piecewise introduction of new process technology into shipyard plans and programs;
3. retention of traditional production management approaches;
4. inadequate or non-existent training of managers and workers in the use of the new technology, as well as ineffective decision making and communication;
5. lack of product design/production and process technology integration;
6. insufficient performance incentives;
7. inadequate production planning;
8. lack of enforcement of just-in-time delivery and process performance;
9. ineffective quality control and management;
10. casual labor practices and high labor turnover;
11. ineffective marketing, customer communications, long shipbuilding lead time, and consumer control over design, and certain procurements;
12. ineffective, non-responsive, hierarchical organization and management structure;
13. comparatively low level of education and training of workers, staff, and management;
14. lack of effective operational integration and intra-labor as well as labor-management communications and cooperation;
15. inadequate yardwide strategic planning of technological change or piecewise technology introduction;
16. ineffective procurement and inventory management;
17. restrictive union practices, such as work rules, seniority systems, and opposition to technological change or changes in work procedures;
18. lack of effective design for producibility;

19. short horizon management;
20. lack of discipline, loyalty, and commitment by staff and workers;
21. ineffective incentive measures;
22. lack of organizational flexibility;
23. makeshift technology change; and,
24. no yard direction or involvement in product development.

However, much of the investment in new shipyard process technology in the U.S. was as a result not wasted. With lower labor cost, good quality labor, and currency neutrality, an effective technology base, and adequate support facilities and industries should have allowed U.S. shipbuilding productivity to close in on world class standards by now.

#### REASONS FOR LACK OF COMPETITIVENESS OF U.S. SHIPBUILDING

While labor productivity is an important factor of competitiveness, other factors are also important. These can be summarized as factors such as: capacity and technology of the U.S. shipbuilding industry; industry structure; government involvement; training; technology development; management organization; product development and marketing; labor/management relations; defense/industry relations; and total quality management and prescription for commercial revitalization.

U.S. shipbuilding capacity is highly imbalanced in terms of commercial shipbuilding requirements. It has a large infrastructure but insufficient support technology as well as excess outfit capacity. At the same time the industry suffers under inadequate design and product development capacity, and inadequate design production integration capability. Although many of the modern manufacturing technologies were developed in the U.S., there are many examples of insufficient or improper use of advanced manufacturing methods and planning in U.S. shipyards. Similarly technology diffusion takes too long. Capacity should be rationalized and process technology be developed and introduced truly as a part of an inte-

grated product design, producibility, production, assembly plan. In the past U.S. shipyards have often introduced new process technology because other advanced shipyards had done so and not as a result of discovery of a real need for the new process technology.

Another factor for lack of competitiveness is the structure of the U.S. shipbuilding and related support industry which is highly fragmented and often uses ineffective product strategies. It usually relies on the customer to design the product which is then constructed as a custom-built ship. Supplier-shipyard relationships are not effective with little mutual technical and marketing support. Relations with financial institutions are also either non-existing or ineffective as yards traditionally relied on the U.S. government for financing arrangements. As a result most yards have little if any experience with creative financing, particularly if it involves international financial markets. There is little coordination of strategy among the industry and intra-industry as well as industry/government relations are more often adversarial than mutually supportive or promotional.

Past and existing government aid is fragmented and largely counter to good incentives. It has rarely helped to improve the competitiveness of the industry. Even government support of technology development is oriented mainly towards naval technology/science and largely theoretical manufacturing technology development. Government in the past did not support product development nor the development of more effective shipyard management.

It is curious to note that government frequently preferred to offer aid with strings attached instead of real incentives.

#### MANAGEMENT ORGANIZATION

The organization of most American shipyards did not change in many years and traditional hierarchical structures (with 9-18 levels) are still the norm. There is very little delegation of decision making to the lowest competent level nor are there serious efforts being made to level the structure to only 5-7 levels. Information systems are



still hierarchical and as a result decisions take a long time, are highly fragmented, and often ineffective. Few yards have real time information feedback or real time information management. Data base management systems which also tie into supplier and customer information management systems.

Product development and marketing have been a low priority and few U.S. shipyards have well developed marketing organizations. Similarly, product orientation has seldom been backed up by formal market research and market development. The development of an effective market strategy would require:

1. meaningful product definition,
2. effective comparative advantage study,
3. focused product development and,
4. well structured product design and concurrent design-engineering-procurement planning and production.

It also requires product market follow-up and audit as well as product maintenance. Successful foreign shipyards as well as U.S. aircraft manufacturers, as two examples, do all of this as a matter of routine. U.S. shipyards had to be prodded by Maritech funding into product development and even then only developed a new product or ship design but performed little of the supporting activities listed above.

The industry has little experience in the establishment and nourishing of customers, and for that matter supplier, relations. It must learn to develop product-to-client "performance" requirements and build long-term relationships. Although total quality management (TQM) has been touted by the industry for some time, it is now largely introduced as a me-too perfunctory exercise and not as an essential prescription for commercial revitalization. TQM requires:

1. 'customer first' orientation;
2. streamlined organization;
3. elimination or reduction of government "aids" which are unproductive;
4. improved, integrated, and cooperative supplier relations;
5. market-oriented product development;
6. effective technology development and application;

7. management and worker training; and
8. effective relations with financial institutions and creative financing.

TQM means a move toward excellence not just in the product design and manufacture but also in:

1. management commitment;
2. customer orientation;
3. employee involvement;
4. continuous improvement;
5. enablement and empowerment of employees; and
6. definition, control and improvement of key processes.

The major reasons for failure of TQM in some U.S. shipyards has been the:

1. lack of strategic planning;
2. lack of focus on core competencies;
3. obsolete out-dated cultures; and
4. lack of results oriented management.

These are necessary to make TQM work. TQM cannot just be considered a set of basic tools and methods.

The effective implementation of TQM requires leadership, strategic intent, and boundary setting constraints. Similarly, metrics for TQM in shipbuilding must be established by the setting of effective benchmarks. These in turn must be more than simple goals - they must be achievement plans.

The labor/management relationship must be improved and changed from adversarial to cooperative relations. This will require involvement of labor in many decisions, a move toward permanent employment, and a real participatory working environment. Labor career training should not just be restricted to basic skill training but become true opportunity training. The U.S. shipbuilding industry spends less on training than any other U.S. industry and all foreign shipbuilding industries. This cannot go on if industry is to succeed.

The industry will only be able to attract young, competent workers and staff if it projects an image of professional opportunity which it does not do now.

The average age of workers in U.S. shipbuilding is well above that of any other U.S. industry including shoemaking. Similarly the percent-

age of management and senior administrative personnel in U.S. shipbuilding who have degrees in their area or discipline is lower than in any other industry. Few ever took formal courses in shipbuilding, manufacturing, engineering, or management.

#### COMPARATIVE PRODUCTIVITY AND COMPETITIVENESS OF U.S. SHIPBUILDING

As noted before American shipyard workers are probably as good as any other industry's individual workers; yet U.S. shipbuilding labor productivity lags far behind that of leading shipbuilding countries. The reason for this apparent conflict is the lack of effective workplace organization and management. American shipyard workers often spend less than 40% of their work time actually performing their assigned work. The reasons include:

1. disorganized work assignment;
2. interference with other on-going work;
3. tools and/or material required for the job not available, incomplete, or wrong;
4. insufficient information supplied for effective performance of the work;
5. wrong work assignment;
6. uncoordinated and often unnecessary inspection and tests;
7. lack of protection against weather and inappropriate work environment;
8. lack of effective work and work sequence planning;
9. ineffective or unavailable quality control requirements (these are often not measurable or interpretable);
10. inadequate supervision and management; and
11. inadequate worker skill.

The last is usually the least important in accounting for the low gross labor productivity in American shipbuilding.

As noted in Table I, U.S. labor shipbuilding productivity is only 35-50% that in good Japanese and European shipyards. Much of this difference is caused by management, organizational and workplace environmental deficiencies which could be overcome by a radical restructuring of the industry.

Investigating typical work environments, for example that of a

structural welder, it was found that the total time the average welder actually welded was 141 minutes out of 480 minutes of a work day (E. Frankel, 1992/93). Furthermore part of the time the performance of the welder was less than optimum because of various interferences. The low percentage of actual work time was caused by lack of materials, work pieces or tools, ineffective alignment, unavailability of proper hold down clamps or other tools, and various other factors.

By comparison welders performing similar work in a Japanese shipyard achieve actual welding times of over 308 minutes in a work day (E. Frankel, 1992/93).

U.S. shipbuilding productivity also suffers under a lack of learning curve effects which benefits most foreign yards which usually have many repeat orders of identical ships offered by one or more yards.

#### SUPPLY CHAIN MANAGEMENT

Shipyards require effective coordination of supply to assure not only just-in-time delivery but also

1. integration of design of procured items into the vessel design;
2. coordination of systems development and integration as systems usually include supplied equipment and components from many sources;
3. integration of quality management standards and procedures of equipment and components management;
4. interface management to assure that suppliers coordinate interface requirements;
5. standardization of test and acceptance procedures; and
6. coordination of maintenance and spares requirements.

These and other supply requirements are all part of effective supply chain management which should induce yards to work with suppliers as one large procurement and manufacturing family in which each member has an equal stake in the success of the project - the delivery of the vessel.

If suppliers are simply low-cost sources of delivery of equipments or components that meet the basic specifications, without con-

tern for interface coordination and the above-mentioned requirements, then supply is not effectively managed and will cause major overruns in costs, schedules, and defaults.

#### Difference Between U.S. and Foreign Commercial Shipbuilding Procurement costs

The difference between American and foreign shipbuilding costs includes labor cost, material cost, equipment cost, facility use cost, and financing cost differentials. Labor cost differentials were discussed with comparative shipbuilding labor productivity. There it was found that while U.S. shipyard workers are equally proficient as an individual, their actual output is only about 40% of that of the foreign shipyard worker.

Considering that actual, burdened shipyard labor costs in the U.S. are now about 68% of those in Japan and Europe when taking the low value of the dollar into account, the comparative labor cost per unit output becomes 58.82%.

Another issue related to is higher management or overhead costs which in a typical U.S. shipyard are about 50% higher than in a comparative Japanese or European yard. This is due to both a larger percentage of administrative staff, and larger inventory and tooling costs. Both of these are the result of less effective material and work flow management. Another hidden cost to U.S. shipbuilders is associated with higher costs of government regulation and inspection.

Material and supply costs in an American yard for a typical commercial ship will usually be 15-30% higher than those of a comparable foreign yard because of

1. higher U.S. prices,
2. low volume of purchases,
3. competitive procurement which involves lengthy expensive bidding,
4. special material and component orders and requirements,
5. long delivery time,
6. financing costs of procurement,
7. test and inspection cost, and
8. administrative costs of procurement.

Not only are U.S. shipyard procurement costs higher but because yards

have no long-term relationships with their suppliers, supplies are often not delivered exactly to specification, as only general and not detailed requirements can be specified.

#### FINANCING AND FINANCIAL COST DIFFERENCES

While most foreign shipyards have close links with financial institutions and are therefore able to assist clients with ship financing, U.S. shipyards basically rely on government construction loan and ship mortgage loan guarantees which permit reduction of certain ship financing costs. There are many creative methods of ship financing such as tax advantaged financing; purchase-sale-leaseback financing, which uses depreciation tax credits; exchange credits; and prepaid charter financing. These are effectively used by foreign shipyards in assisting their clients in raising methods the required investment capital.

Although U.S. government construction and mortgage loan guarantees may reduce the cost of ship financing, they are mostly attractive to owners who cannot raise investment financing at equal or lower cost creatively in the financial markets because of their own condition.

Although government guaranteed loans usually carry interest of 1-2% less than other collateralized loans, the recent rapid increase in U.S. interest rates may make even such guaranteed loans expensive compared with loans in lower interest rate countries in Japan and Europe.

Borrowing in these countries exposes the borrower to the cost of a continuing decline of the dollar. But if the dollar does not decline further but strengthen as a result of higher U.S. interest rates, then borrowing in foreign capital markets may become a real advantage over even U.S. guaranteed loans unless the borrower is not credit worthy abroad.

Another financial cost issue is the financing of the cost of construction. The average U.S. yard requires 2-3 times as long to build a similar commercial vessel than a good Japanese, European, or Korean yard. At today's interest rates

this longer time adds 7-10% to the cost of construction because construction costs are extended by 9-18 months.

#### ADDED COSTS OF FACILITY USE

Longer construction time implies longer use of major facilities and equipment. If a building dock is used 12 months versus 4 months between keel laying and launch of a commercial vessel, then the cost of occupying the dock (and related equipment) for the added 8 months must be accounted for. Furthermore the cost of the loss in opportunity of using the dock and associated equipment for other construction or repair work must be accounted for.

These costs readily add 10-18% to the cost of construction of a typical commercial ship but are often ignored in calculating the real cost of construction on the false premise that the dock has been fully depreciated. This is false financial accounting.

#### U.S. SHIPBUILDING COSTS

As discussed before U.S. shipbuilding costs differ from those of foreign yards in

1. labor costs;
2. shipyard management and administrative costs;
3. supply and procurement costs, including added inventory holding costs;
4. financial costs of construction in process;
5. facility utilization costs ; and
6. cost of ship financing.

Even if the cost of ship financing, which is not under the control of the shipyard, is left out, it has been shown (E. Frankel, 1993) that U.S. shipyards suffer under severe cost disadvantages which, if all accounted for, make them non-competitive. A typical product tanker, for example, costs at least 70-110% more build in a U.S. yard than

There are some exceptions to this such as the low overhead and basic facility yards on the Gulf Coast which can build such ships at a cost which is only slightly higher than that of an average foreign yard. They achieve this by sticking to basics in terms of facilities and management and by attracting a com-

petent, committed work force- Some are nearly greenfield yards with very low facility costs, but this is not the case with most, and particularly the larger, U.S. yards.

#### WORLD SHIPBUILDING PRICES AND COSTS

World shipbuilding processes generally weakened in 1993 but are becoming firmer now in 1994 (Table 111). Profit margins in Japan and Europe for tankers and bulkers are between 0% and 11%, and only a little better for container ships. The average cost of constructing a tanker was about 95% of the price. A 5% profit margin, while reasonable, does not allow for large errors.

At the same time the average secondhand price as a percentage of newbuilding prices has steadily declined from 55% in 1988-90 to 38% between 1992 and 1994, even though the average age of secondhand tonnage traded was less during the more recent period (Fearnleys, (1990-94). This implies a continued pressure on newbuilding prices.

	<u>DWT</u>	<u>World Price</u>
<u>Tankers</u>		
L c c	280,000	95.0
Suez Max	140,000	62.0
Aframax	95,000	44.0
Handy	40,000	32.0
<u>Bulk Carriers</u>		
Cape size	155,000	46.0
Panamax	70,000	28.5
Handymax	40,000	25.0
Handy	30,000	21.0
<u>TEUs</u>		
<u>Containerships</u>		
Post-panamax	5,200	87.0
Post-panamax	4,400	78.0
Panamax	3,200	60.0
Feeder	1,200	24.0

Table III - Newbuilding Prices in Millions of Dollars (1993)

This is a difficult market in which to compete with a revitalized U.S. shipbuilding industry, whose costs will continue to be significantly higher than those of its competitors, notwithstanding the new

## U.S. National Shipbuilding Initiative.

### ECONOMIC EFFECT OF NATIONAL SHIPBUILDING INITIATIVE

The National Shipbuilding Initiative (Marine Log, 1994) announced with great fanfare, and embraced by the industry in general, as a savior will do little if anything for the long-term revival of American shipbuilding. It provides some basic funds for the development of shipyard products (designs) as well as for the improvement of some facilities and, most importantly, for construction and mortgage loan guarantees. While product design may, for the first time, provide yards with unique products for offer to shipping, the few products under development by individual yards are too specialized to interest a significant market. They appear to be designed more to aim at a particular, often small, customer than at a significant global market segment. In other words these product designs are not broad enough for a determined world wide marketing effort.

Similarly investment in shipyard production technology is highly fragmented to an extent where it will improve several yards marginally but no yard significantly enough to make it internationally competitive.

Finally, the \$1.5 billion in loan guarantees are not going to save the industry because they provide only a marginal incentive for some U.S. and mostly foreign owners, and are quite limited in scope considering current U.S. shipbuilding costs.

The loan guarantees do not attract large customers and they are only offered briefly as their continued availability depends largely on future Congressional action.

### IMPACT OF GOVERNMENT INVOLVEMENT IN U.S. SHIPBUILDING AND PROTECTION

Since 1921 (or 1936 depending on interpretation), the U.S. government has been involved in the direct support and protection of U.S. shipbuilding.

Construction Differential Subsidies. (CDS) to shipyards, a major component of the government's

support system to shipyards, have been a major cause for the decline in U.S. shipbuilding competitiveness and productivity. They isolated the industry from competition and encouraged productivity decline. Together with large-scale reliance on government contracts, they also caused an inflation in shipbuilding bureaucracy and administration. It further isolated U.S. shipbuilding from the international shipbuilding market and essentially made it a ward of the state, depending mainly on Congressional budget decisions for both commercial and naval ship orders. Government dependence also affected labor-management and supplier-shipyard relationships as many conditions were written into government shipyard support and order requirements.

Thus the industry puts its faith and fortune at the mercy of government programs at a time of declining government orders and ability to economically assist the industry. True new government aid, such as loan guarantees, are now available for export orders as well, but there is a serious question if these aids will help improve shipbuilding competitiveness or simply provide some stop gap measures to limit the rate of decline of shipyard orders or employment.

While it is difficult to estimate the real cost of Maritech and loan guarantees to the nation, these costs will ultimately be on the order of \$400-600 million, depending largely on changes in the rates of interest and defaults on loans.

While this may be a small sum to pay for the revival of an industry which employs 65,000 directly and about 40,000 indirectly, with revenues of nearly \$10 billion, the question is if other strategies may not provide better long-term payoff in improvements in competitiveness.

The small efforts in product development and process improvement are too fragmented to really make an impact. They may assist a few yards to attract customers for a few short-run orders, but will not make U.S. yards real competitors in tanker, bulker, or container ship construction in the world market. Similarly loan guarantees will attract a few, mainly foreign orders, because they provide easy if not cheap credit, but they will do lit-

tle to improve American shipbuilding competitiveness.

It is very likely that shipyards will become dependent on these aids. whenever these aids are discontinued, which they ultimately will have to be, yards will essentially be where they were before - dependent on government aid for survival.

#### ALTERNATIVE APPROACHES TO U.S. SHIPBUILDING REVIVAL

American shipbuilding does not need temporary financial aid and protection, but a radical structural change. It must reinvent itself to become a mean, lean, productive, and creative ship production industry, unhampered by government rules and restrictions. It must be able to compete worldwide under terms and conditions of other global industries without restrictive requirements in procurement of supplies or sale and financing of its products. It must be able to joint venture or work with anyone worldwide.

If government wants to assist the process of revitalizing U.S. shipbuilding, it should offer real meaningful incentives for productivity improvements. These could be:-

1. income tax incentives;
2. free export or trade zone incentives (where shipyards can import supplies free of duty or restrictions for use in ships for export or even domestic clients),
3. export incentive credits (when yards obtain direct or tax incentives on export earnings),
4. tax incentives for money spent on training, and facility improvements, and more.

There is an array of opportunities for productivity improvement incentives. These in turn should be tied to radical reengineering of American shipyard firms. This must be done using a bottom-up approach with a view to strengthening the productive sectors and reducing the administrative sectors of the industry.

There is no reason why U.S. yards cannot build tankers and bulk carriers in 6 months and container ships in 10-12 months. It should be possible to develop a whole series of modern designs for families of

the principal ship types which each interested yard can then adapt to its particular production approach using an integrated design/production approach.

It should be possible to revamp our yard/supplier relationships by bringing in foreign suppliers and developing families of suppliers and yards which agree to long-term relationships, integrated coordinated design, just-in-time planned delivery, and quality management standards. Such families would also work jointly in marketing and in developing creative approaches to construction or ship acquisition financing.

Shipyard management must be restructured by delegating decisions to the lowest competent level and reducing the levels of management to less than half the current number. In general shipyard management and administration should be reduced by 50-60% over a 3-year period. At the same time more and more shipyard workers should be made permanent employees. Training and retraining should become an integral part of work and productivity enhancing.

Total quality management shipyard procedures and standards should be developed and adopted by suppliers and yards alike, and test/acceptance procedures be standardized. In parallel all workers and supervisors should be trained in effective TQM.

Most U.S. yards maintain old, decrepit facilities which will or should never be used again. They should abandon them and consolidate their activities in the more modern effective facilities.

During the 1985 shipbuilding recession, the Japanese shut down all obsolete yard facilities, invested only in modern facilities, and significantly improved both productivity and output capacity of the remaining yards. Comparative investment effectiveness in specific yards should be determined before improvements are made and moneys only invested where comparative productivity improvements are highest.

#### CONCLUSIONS

For U.S. shipbuilding to revive and become world class will require more than temporary govern-

ment initiatives such as Maritech and ship construction loan guarantees. There is a need for radical restructuring and reorganization of the industry as well as government relations with it. The industry must become truly free to perform as a global industry be provided meaningful incentives and not temporary aid. This must be done to achieve worldwide competitiveness in U.S. commercial shipbuilding and to claim its rightful place among the leading shipbuilders of the world.

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# Tee-Beam Manufacturing Analysis: Producibility of

## Panel Stiffening Elements

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### ABSTRACT

This paper analyzes the manufacturing of tee shapes for stiffening ship structure. The traditional method of deflanging hot-rolled I-beams (producing I/T shapes) has been compared to the practice of fabricating tee-shapes from plate. A group of more than 1700 I/T shapes, used in the DDG-51 class vessel was used for comparisons. To produce the I/T shapes for one DDG, flanges are stripped from more than 700 tonnes (690 long tons) of I-beams. The flange material removed amounts to 25% of the weight of the original I-beams, totaling approximately tonnes 172 tonnes (170 tons). This represents a material loss of 25%, easily in excess of \$90,000.

Prior review of design criteria for several DDG stiffened plate structures showed that fabricated tees could replace I/T shapes, resulting in weight savings averaging 18%, while still maintaining required strength. An evaluation of methods to produce tee sections was undertaken and the concept of "net shape" fabrication of tee stiffeners was discussed. Both fabricating and stripping methods were considered including newer technologies such as plasma cutting and laser cutting and welding. Mock-up testing was performed using several candidate technologies and the results compared. Plasma-arc cutting reduced distortion on 12.2m (40 ft) test beams by 50% compared to oxyfuel methods. Economic analysis revealed that fabricated tees were less costly to produce than deflanged I-beams, and that handling functions were the greatest cost element of the traditional oxyfuel cutting methodology.

### INTRODUCTION AND SCOPE

The information presented here is summarized from the final report of a project funded by the National Shipbuilding Research Program (NSRP #7-91-4). The project was undertaken to compare the relative merits of various schemes for producing panel stiffeners, considering design aspects of fabricated tees versus those stripped from I-beams, and evaluating various methods of producing tee shapes, considering current as well as new technologies. Although fabricated tees may offer some benefits, it is not a foregone conclusion that fabrication is the best approach for every situation. Thus, the quality and relative economies offered by the various processes for both stripping and welding have been considered.

Most combatant ship designs have required tee shapes for stiffening panels (decks, shells, and bulkheads). Typical mill practice involves splitting I-beams down the center of the web, e.g., a 304 mm (12 in) deep I is split into two 152mm(6in)tees, as in Figure 1. This does not provide a shape with the best section properties for ship panel stiffening, since I-shapes are primarily optimized for building construction. A convenient solution has been the traditional approach of removing one pair of flanges, so that the 304 mm (12 in) I becomes a 304 mm (12 in) tee, as in Figure 2. This yields a section with adequate properties for ship panel stiffening, and provides a readily available source of material of convenient length for processing. Although this requires minimal labor

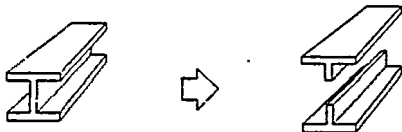


Figure 1. Split I-beam

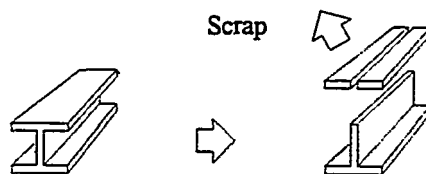


Figure 2. Stripped I-beam



input on the part of the shipyards, it produces a significant amount of scrap material. Also, current production methods frequently cause distortion or damage to the members.

Since the design process can yield values for section properties (the “design shape”) which are not necessarily exactly those of a section available from steel producers, the “next larger” available shape is chosen. Flange and web thicknesses, and widths of available shapes, may also be disproportionate to those of the design shapes. Thus, the convenience of selecting from a catalog results in greater weight and cost. The alternative is to design a shape to be built from plate. Plausibly, plate material is available in a greater range of thicknesses, so that a fabricated tee section could be made with dimensions conforming more closely to those of the design shape. Furthermore, rolled plate material thickness, and therefore weight can be more accurately controlled by steel producers, allowing better conformance to design weight requirements.

Fabricating tees from plate is not at all new or unique,<sup>12,34,5</sup> but has been limited to the X&emt?S production of tee sections where the section size or shape is not available as a hot-rolled I-beam, especially in the case of deep webframes, or in the allowed case of extremely lightweight sections. Usually, custom production of mid-range sections has not been considered cost-effective. There can be several reasons for this, especially when typical shipyard hand-lit and manual or semi-automatic welding methods are used:

- A wide variety might be needed with perhaps little repetition of specific designs,
- Designing custom shapes adds time to the design phase of the ship,
- Estimated yard labor costs are typically high compared to steel costs,
- Traditional fit-up and tacking of flange to web is viewed as difficulty and
- Traditional manual and semi-automatic welding methods are labor intensive and produce excessive distortion.

Newer welding technologies, such as laser welding and high-frequency resistance welding have challenged these assumptions, and mechanized equipment for producing tees has been continuously improved but neither have made significant inroads into shipbuilding practice. Increasing mechanization and computer integrated manufacturing (CIM) will impact this decision process in the future.

## PROBLEM STATEMENT

I-beam stripping is typically done using the dual-torch Oxyfuel Cutting (OFC) process, with some sort of mechanized gantry or other device to move the torches over the beams. While this equipment is simple and reliable, the use of the OFC process tends to result in certain characteristic problems which frequently require rework as shown in Figure 3. Unacceptable warpage (camber) is caused by the high heat input associated with OFC. Webs may be damaged by gouges due to errors in torch tracking. Frequently, the torches are offset from the web to avoid this damage; this practice leaves excess material and weight and can make welding of a tee to a panel more difficult especially when mechanized panel line equipment is used. Also, 25% of the purchased material is turned into scrap.

Hot rolled shapes are manufactured to criteria given by ASTM A-6<sup>26</sup>, which specifies tolerances for overall dimensions (such as section depth), allowable camber, flange-to-web tilt alignment of the web with the centers of flanges, and other criteria. The tolerance limits of A-6 may exceed the limitations of fabrication documents for structure alignment. In some cases, A-6 allows enough offset that webs may be off-center in different directions by more than the thickness of the web material. Sections are allowed a difference in depth that sometimes exceeds flange thickness. Shown in Figure 4, these conditions are often discovered when tees are butted together at unit erection and usually require rework of some sort (patching weld build-up, etc.). Imposing stricter tolerances on rolling mills causes costs to increase. Fabricated shapes can be built far more accurately as a matter of routine.

The use of I/T shapes may induce a weight penalty on vessel design whereas a fabricated shape can

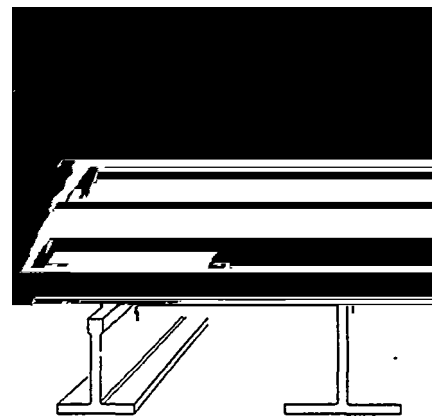


Figure 3. Problems in OFC Deflanging

produce needed properties at reduced weight. The NSRP report includes a design review which calculated the true size of sections required<sup>30</sup> for stiffening several deck bulkhead and shell assemblies. Using these calculated design shapes, fabricated tees were designed from plate material using thickness commonly available. The fabricated tees had the same outside dimensions as the I/T's in use. In every case, these fabricated tees weighed less than the I/T's, with an average weight savings of 18% for the structures considered. Fabricated tees may also save weight in another way. Surveys of as-received product weight reveal that actual weights of hot-rolled shapes are generally 4-5% over theoretical weights, whereas as plates have been measured consistently at within 1% of theoretical weight.

Design specifications may not allow fabricators to take full advantage of these weight savings. The DDG-51 Ship Specification for instance, allows fabricated shapes to be substituted for stripped I/T's, but only if the fabricated shapes have sections identical to the I/T's they would replace.

Finally, many mechanized welding methods run at faster speeds than burning methods. Depending on the technology and equipment used for production fabricating may require less shipyard labor. The problem becomes one of overall strategy in evaluating how structures should be stiffened and producing the required shapes in the most cost-and weight-efficient manner.

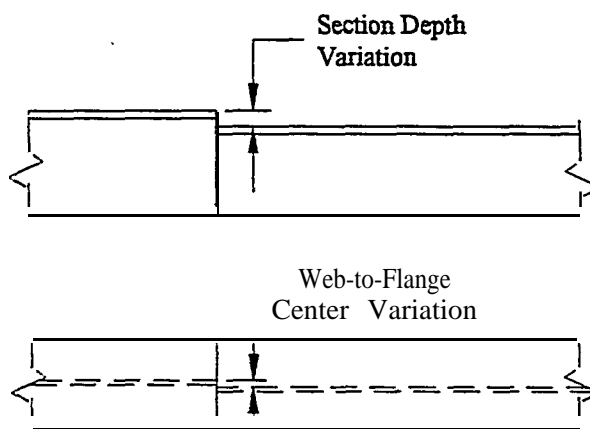


Figure 4. Some Variations Allowed by A-6

## APPROACH

Analysis of tee beam manufacturing took these steps:

- Existing and advanced technologies for deflanging I-beams were evaluated
- Technologies for welding tees were evaluated
- Relative economies of the methods were compared
- Small-scale mock-ups evaluated promising technologies as to speed, distortion and quality, and
- Where possible, large scale mockups verified the results of small scale mockup tests.

This approach had to take into account some very practical limitations. First a target population of tee sections was needed for this analysis. To provide a well-understood group, the DDG-51 class vessel was chosen. Currently in production at Bath Iron Works and Ingalls Shipbuilding Division the DDG hull uses thirty different I/T shapes produced from I-beams which range from W6x9# to W20x55#. As shown in Table I, more than 26 km (80,000 feet) of I-beams weighing 701 tonnes (690 long tons [of 2240 lbs]) are deflanged yielding 527 tonnes (519 long tons) of tee shapes and 174 tonnes (171 long tons) of scrap, resulting in a significant loss (over \$90,000 at recent prices).

Second any type of mock-up testing of new technology had to be done on available equipment developed to meet existing needs. Generally, existing equipment is not capable of making long, parallel simultaneous cuts. Thus, laser and water-jet cuts had to be done sequentially in two passes, on relatively short pieces of material. While cut-edge quality and speed could be compared it was difficult to estimate the kind of distortion which might be experienced using these technologies for comparison to that produced by the traditional dual-torch oxyfuel method. Fortunately, plasma-arc cutting equipment was loaned to this project and installed on a production bar stripping gantry, so that beams 12.2m (40 ft) in length could be deflanged.

Finally, an economic analysis Of production costs and rates is limited in the number of potential scenarios treated and relies on some basic assumptions. Review of manufacturer's data can provide much information but the final cost will depend on the implementation of the method and the degree of utilization (duty cycle) actually maintained by production personnel. This project has attempted to evaluate a number of these factors to determine an optimum approach to manufacturing stiffeners. Knowing that local conditions may require different solutions to the same problem a further goal has been to provide enough information to allow the reader to evaluate different situations.

20	55	44.18	10.82	19.7%	20	18	360	19,800	15,904.8	3,895.2
Total Pieces:					1,716					
Total Feet:					82,441					
Total Wgt (#):						1,545,469	1,163,603.1	381,865.9		
Wgt. (LTons):						690	519	170.5		
% Scrap Loss:								25%		

## PROCESSING AND PRODUCTION CONCEPTS

Two distinct scenarios have been used for processing tee sections. Stripping methods have generally used a batch-type approach with multiple bars being deflanged simultaneously by a gantry moving over the parts, and fabricated tees have traditionally been produced by a continuous method with a two pieces (web and flange) being passed into a fixed welding head to produce a single tee. Stiffener welding gantries, made to simultaneously weld several stiffeners to plates, can also be used to manufacture batches of tee shapes.

The advantage of batch processing is greatest when the cost per process insulation is relatively low compared to the cost of the gantry or station. If four I-beams can be processed at once, many of the cost elements per cycle are divided by four. An oxyfuel deflanging gantry is a good example. Torch carriages can be added to a gantry for a relatively low cost. In contrast higher-speed methods like laser cutting may cost 100 times as much as oxyfuel per cutting head and can reasonably be expected to be more cost-effective only in a continuous-process mode, gaining their advantage from higher processing speed.

Continuous processing has been used for many installations where high speeds are achieved and the cost of the process is relatively high. Usually, continuous-mode production is not very flexible, as machinery is designed to do large volumes of particular sizes, either very heavy sections (e.g. bridge beams) or very light, as in shapes for mobile home frames produced by High Frequency Resistance Welding (HFRW). The concept of making many different sizes at a shipyard in any kind of "just-in-time" approach is not intuitive. Nonetheless, if the entire volume of stiffening elements is considered it may be economically feasible to justify more than one machine. Further, the operating range of equipment may be expanded by minor modifications in design.

Beyond the relative merits of batch and continuous processing, other aspects producing stiffeners should be considered. Figure 5 shows the production path from as-received mill product to the final detail, of three approaches to providing stiffening elements for shipbuilding. Method A is the deflanging, or I-to-T stripping, in which I-beams are received from steel mills and the flanges are burned off and stock lengths of tees are inventoried for later cutting into structural details. Scrap, averaging 25% of the new material, is generated at the deflanging stage and must be removed; rework may be required; significant handling is incurred and material must be supplied and inventoried both upstream and downstream sides of the

stripping facility, well in advance of production requirements. When the schedule finally calls for production of specific tee elements, the previously deflanged beams are drawn from stock laid out, and cut to the desired length and configuration. Scrap is generated at this stage as well.

Method B shows the fabrication of stock-length tee sections from plate or strip material. Steel bars or strip are provided either by cutting plate or purchasing hot-rolled flats. Scrap may or may not be generated depending on the approach. Flange and web are aligned and fit, typically with substantial manual effort and joined usually by semi-automatic welding methods. For light sections, welds are usually much larger than needed for strength. Significant distortion may occur during welding, requiring rework. Little scrap is generated but handling may be extensive. Again, material is inventoried both upstream and downstream in the production flow to assure that there are tees available for cutting into detail pieces when schedules require. The final step is the same as done in A.

Tees can also be fabricated from pieces of standard "Universal Mill" bar stock. One foreign shape rolling mill provides such fabricated sections which fit into gaps in the catalog of split hot-rolled I-beams. This only establishes another catalog, and still forces tradeoffs between required strength and final weight because these shapes are still not optimized to the design goals of the vessel. The thicknesses and widths of universal mill bars are sufficiently varied so that weight compromises may be less severe than those forced by stripping I-beams to tees. If a supplier uses this approach fabricated tees produce no scrap until the final detail cuts are made.

A and B are fairly well known and used; the differences being only of scale. The traditional approach is that tees are produced by method A if there is an I shape with reasonably close sectional properties, and method B is used everywhere else. Because the final use may not be known at the time tees are welded, welds are usually designed for 100% efficiency, even though in many applications, welds which join these tees to decks or shells need only be 60-70% efficient.<sup>10</sup>

For production of stiffening elements on a shipset scale, method C is a different approach entirely. All web and flange sub-pieces would be cut to final shape from flat plate, and joined into a "net-shape" stiffener. Scrap is generated only in the plate cutting phase, and handling and inventories could be significantly reduced. Through efficient nesting of material, scrap could be minimized. The main concern is that tracking of pieces is critical to success. The ideal reduction of inventory would have flange and web piece being cut at nearly the same time, and immediately being routed to automatic

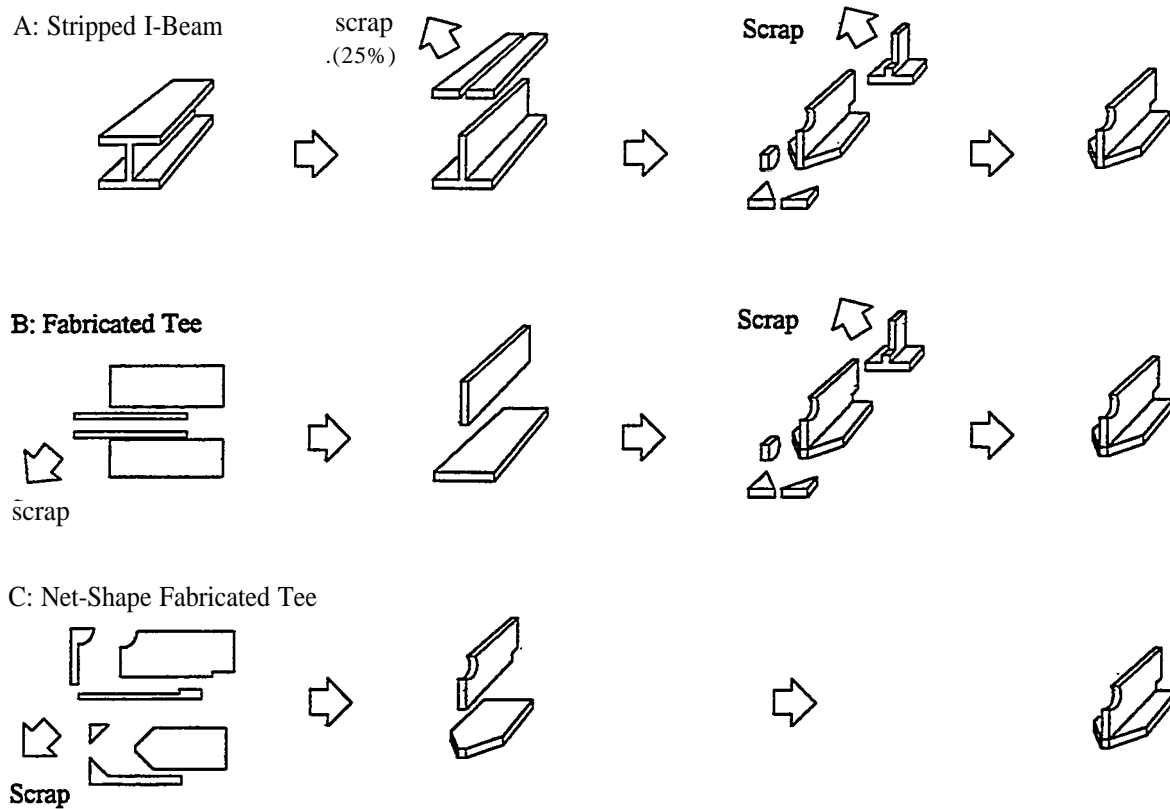


Figure 5. Practices of Tee Stiffener Production

welding workcells. The concept of efficient nesting, however, might require that some inventory of web and flange parts be maintained as the processing of different thickness plates dictated. This implies a thorough method of storage and retrieval on a scale not used before. With the increased use of computraized job tracking and bar-coding on the shop floor, the question becomes more one of execution than one of possibility.

“Net shape” production of tee elements also requires the use of automatic welding equipment to be successful. Manual fitting and tacking must be eliminated and welding must be reliably done at the highest practical speeds. Through computerized integration of all job factors, including design and welding data as attributes of part identity, the correct size and shape of welds can more nearly match design requirements. New methods, such as laser welding, offer potential for full penetration welding at high speeds with minimum overwelding.

A further demand on equipment flexibility is that in addition to different sizes, many different lengths must be produced. Typically, tee fabrication equipment is used to produce standardized long pieces only.

At first it might appear that method C is not used **at all, but that is not really the case. Large and complex** fabricated web frames are tee sections nonetheless. The use of method C to produce smaller or shorter tees in any significant volume has not been reported.

An aspect of stiffener production which is seldom considered comes from the fact that a shipyard must buy and inventory a enough I-beams to meet the production rate of a beam stripping facility. This facility then makes a “second inventory” of shapes which are issued out and processed later into useful ship parts. The cost of the extra material needed and the lead time necessary to support these schedules are difficult to clearly state. A “net shape” approach does away with all of this, but the implementation is no simple matter.

## CUTTING AND WELDING METHODS FOR STIFFENER PRODUCTION

The methods review catalogued a number of cutting and welding technologies, emerging as well as traditional, which could be applied to the manufacturing of tee sections for stiffening ship panels. The methods were screened and the more promising techniques identified for further analysis of cost quality and productivity, small-scale mockup testing, and where appropriate, large scale mockup testing.

Machinery for producing welded tee stiffeners should beat least as productive as that currently used for stripping, but more modern methods of deflanging may exist or could be developed. These methods should be reviewed alongside the potential welding techniques, and the method with the lowest overall cost chosen for production.

This phase attempted to determine

- 1 If a given process can produce a target population of various tee shapes,
- 1 What production rates are possible,
- c What acquisition and consumable costs for the equipment are, and
- 1 The dimensional and surface quality the process yields.

Relevant literature and experiences of those in other industries were studied to determine the potential of various methods for producing tee sections. New technologies were considered especially those which promised greater efficiencies. Since there are so many variables in the configuration of a system capable of dealing with shipset quantities of tee sections, a study of this nature must necessarily be qualitative rather than quantitative.

Once methods were identified those most likely to produce shipset quantities of tee sections were scheduled for small scale trials, and evaluated to

establish modifications might be necessary for making the method into an efficient production tool.

The following methods were selected for review, based on demonstrated success in similar production situations, or, in some cases, on the potential for high speed or high accuracy processing. In the discussions which follow, costs are estimated based on the process equipment at its simplest level, without extensive material handling equipment. In general, the addition of in-feed and out-feed conveyors and stock and scrap handling equipment could add as much as \$.500,000 to the costs listed

### Cutting Methods

For deflanging of I-beams, the process must cut through the thickness of flange and some amount of material in the radius region between the web and the flange. Flange thickness for the target group shown in Table I ranges from 5.2mm (0.205 in) for the lightest section (W8x10#), to 17.7mm (0.695 in) for the heaviest (W18x60##). Radius ranges from a minimum of 7.62mm (0.30 in) to a maximum of 16.5mm (0.695 in). As shown in Figure 6, the maximum thickness was estimated at the flange thickness plus one-half the amount of the radius. Cutting methods identified for this review are summarized in Table II. A brief description of each process follows.

Oxyfuel Cutting (OFC) is the most widely used method for producing tees from I-shapes. The strong points of OFC are the wide base of experience, inherent flexibility, and low equipment cost associated with the process. Its main disadvantages are low travel speeds (.3-.6 m/min (12-24 ipm) as shown in Figure 7), high heat inputs, and relatively large kerf (with the potential for damaging webs when the flame is too close).

OFC equipment is relatively inexpensive to produce and easy to maintain. When an installation for producing tees has been designed the cost of adding multiple torch carriages is only \$2-3k, so that

Table II Stripping Methods

Process	Speed	cost	Consumables	Flexibility	Quality
OFC	0.3-0.6m/min (1-2 fpm)	Low	Gas, Tips	Med	Fair/Good
PAC	0.6-1.8m/min (2-6 fpm)	Med	Gas, Noz., Elctd., Tips, Pwr	High	Good/Exc
LBC	0.3-1.8m/min (1-6 fpm)	High	Gas, Pwr	Meal/High	Good/Exc
AWJC	175-150mm/min (0.25-0.5 fpm)	High	Water, Grit Nozzles	High	
Cold Saw	1.2m/min (4 fpm)	High	Blades, Fluid	High	
Arc Saw	1.5-9m/min (5-30 fpm)	High	Power, Blades	High	Unknown

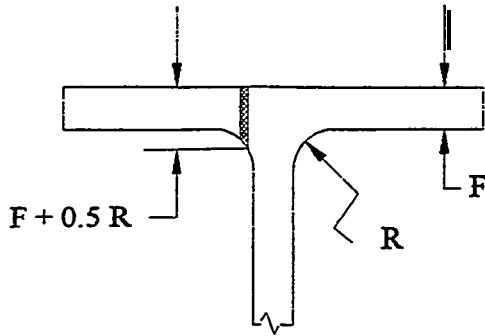


Figure 6. Estimated Thickness of Deflanging Cut

significant parallel processing can be used to reduce the labor costs per foot of processed bar. Fully adaptive control of the OFC process, i.e. dynamic changes to pressures and orifices, has not been explored. OFC's low speeds are a disadvantage for increasing the cost and complexity of equipment. As a result, OFC suffers from a lack of fine control, and this can lead to a certain amount of rework as a result.

Consumables used for OFC consist of oxygen fuel gas, and cutting tips. Fuel gas may be propane, natural gas, or propylene-based. Acetylene is not widely used for large scale operations today.

OFC can cut any thickness of steel used in stiffeners today. This is in contrast with laser and plasma cutting, where the increase in thickness capacity requires a greatly increased capital cost for equipment.

Thermally induced distortion is the highest in OFC, since the process has the highest heat input. Distortion may be reduced by optimization of parameters, use of water sprays, and pre-cambering, but OFC still generates significant quantity of material which requires straightening. Other quality problems arise when a cut is made too close to the web, leaving a scarred or gouged area which must be repaired by welding and grinding.

Plasma Arc Cutting (PAC) provides significant improvements over OFC, especially in speed and reduction of heat input. The process is well understood, equipment is rugged, reliable, and electronically controllable. Prior to the introduction of oxygen-capable plasma systems, PAC was not a serious contender for use in I-beam deflanging because the tolerance band of parameters which would produce relatively slag-free cutting was too narrow, even though cutting speeds could be generally faster than OFC. This is even more important in beam deflanging than in plate cutting. Since the cut is made through the radius transition from flange to web, one side of the

kerf cuts through thinner material than the other side. Any variation in the torch position relative to the web results in a rapid change in thickness to be cut.

Oxygen plasma and inverter-technology power sources have made PAC more attractive. The use of oxygen has resulted in a broader range of travel speeds which produces cuts with minimal slag adhesion. Inverter power supplies offer greater energy efficiency, produce a narrower kerf and are more tolerant of variations in torch-to-work stand-off distance.

Plasma cutting offers the same boost to cutting speed for I-beam processing as for NC plate cutting, with speeds of 2.5 m/min (100 ipm) and faster. Figure 7 shows that speed improvements are significant only in thinner materials (-9.5mm (3/8 in)). As thickness increases, PAC travel speeds drop to values near to those of OFC. For the current range of thicknesses of tee sections in this study, plasma still enjoys a speed advantage over OFC, and as long as the work mix favors the thinner sections, overall processing times are significantly reduced.

Plasma equipment is about ten times more expensive than OFC, but is typically less than one-tenth the cost of lasers, abrasive water jet machines, and cold saws. Inverter-type plasma equipment costs in the neighborhood of \$10K for a unit which will cut all the thicknesses in the target group of tees. To strip one I-beam at least two units are needed more for simultaneous batch cutting.

Electrical power, cutting gases, and torch parts (electrodes and tips) are the major consumables required for plasma cutting. Consumable parts life is markedly shorter with oxygen plasma than that experienced by the older nitrogen plasma systems, but

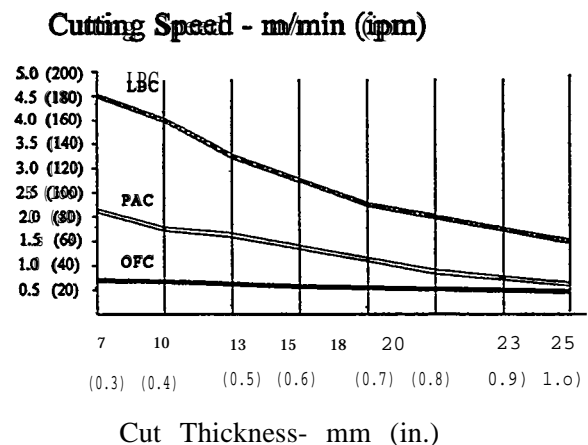


Figure 7. Cutting Speeds for LBC, PAC & OFC

improvements in cut quality, speed and the wider range of parameters at which slag-free cuts can be made have made oxygen plasma dominant in this field.

PAC is reasonably flexible, although for the Purpose of this study, the ability to cut materials other than steel is a moot point for most commercial ship tees. The penalty for ability to cut greater thicknesses is the aforementioned loss of speed, and the need to buy much more expensive equipment capable of processing the greatest thickness, even though these thicknesses may be only a small percentage of the total work mix. Comparatively, since OFC is slow even on thin material, the drop-off of OFC cutting speed with increasing thickness is less noticeable.

As in NC plate cutting, PAC can produce acceptable edge quality. Higher travel speeds possible should produce less distortion than that seen with OFC due to reduced heat input. The use of water sprays and pre-cambering could further reduce distortion.

Laser Beam Cutting (LBC)<sup>13 14 15 16</sup> is gaining in acceptance in the manufacture of light-gauge materials, and power levels have been increasing while cost per kilowatt has been decreasing. The power density available is the highest of the competing thermal cutting processes, so thermally-induced distortion should be the lowest with lasers compared to any of the other available thermal cutting processes.

Carbon Dioxide (CO) lasers in power levels up to 25 kilowatts are available, although the highest-powered units are seldom used for cutting. Multiple-rod Neodymium Yttrium-Aluminum-Garnet (Nd:YAG, often called "YAG") lasers have been produced in versions up to 3 kW, and programs are underway to produce a solid-slab YAG device of 6 kW capacity. Within the distinction of CO<sub>2</sub> and YAG, there are several competing technologies, such as RF-pulsed, fast-flow, diode-pumped, slab, etc. Each may offer specific benefits in speed or quality within its power range, and detailed discussion of these is beyond the scope of this paper. YAG lasers may be used with fiber-optic beam delivery, allowing the laser to be located in a favorable area while the flexible fiber can be deployed in a typical shop atmosphere. This could be a benefit for shipyards, as the special attention to beam delivery required for CO<sub>2</sub> devices is avoided and a greater choice of configurations for tee processing equipment is afforded.

While laser technology is promising, the amount of demonstrated success in heavy-section cutting remains limited and cutting speeds tend to drop off with increasing thickness for a device of any given power level. Considering the high population of

relatively light sections used in surface combatants, this may not prove a serious limitation.

There is potential for very high cutting speeds, although there is not a large volume of industrial experience in thick-section cutting to support this claim. In addition attention to factors such as beam quality, the design of nozzles and beam focusing optics is critical. Development in this area has been demand-driven and therefore limited to thinner materials. Nevertheless, speeds of up to 1.25 m/min (4 fpm) were demonstrated in the test phase of this project using equipment clearly designed for thinner sections.

CO<sub>2</sub> lasers at power levels of 1-3 kW cost in the neighborhood of \$250,000 while the equipment of 10 kW and higher can cost several million dollars. YAG equipment of 2.4 kW capacity is similarly priced to CO<sub>2</sub> equipment of equal power. The cost is dependent on several factors, and due to technology growth may change significantly in the near future.

Higher powered laser devices (14-25 kw) are 10-14% electrically efficient so electrical power is a major cost element. Gases, and to a lesser extent nozzles and lenses, are consumable items. Fiber-optic cables are relatively durable, but terminations and couplings are currently expensive to repair. As this technology grows in popularity, costs for maintenance can be expected to drop.

As with plasma cutting laser systems are power dependent so that for a device of any given power output as thickness increases, cutting speeds decrease disproportionately. Thus, the cost of high-power CO<sub>2</sub> devices limits the use of LBC. While high quality cuts with 3-kW devices have been demonstrated in materials 19mm (3/4 in) and thicker, travel speeds are reduced. Also, at some point thermal attributes of the base metal begin to dominate the chemical reactions in cutting, and some of the advantages of high power density are mitigated.

For materials up to 6.3mm (1/4 in) thick laser cutting yields near-machined quality surfaces. Translating this experience to thick carbon steel with surface rust and mill scale is a significant challenge.

Cold Sawing<sup>8,17</sup> a machining method, is a relatively low-temperature process, and has been increasingly used for cutting structural shapes to length in cut-off saws. Cold circular saws have provided a high quality, cost-effective alternative to band saws and oxyfuel equipment for transverse cuts. The potential advantages of cold sawing are the production of superior edge quality, the ability to cut arbitrarily close to the web of the beam, and the potential for reduced distortion offered by an essentially non-thermal process. A significant consideration is the residue of cutting



fluid which if not removed can affect subsequent weld quality.

Manufacturers claim that cutting speeds up to 1.2m/min (4 fpm) can be achieved in flat plate cutting. These systems often are rated either on volume of material removed or the area of the cut face. Some systems have quoted higher rates, such as 200-400cm<sup>3</sup> (12-24 in<sup>3</sup>) removed per minute, and thus travel speed would depend on blade thickness. Since the saws are very precise, the process may be adversely affected by the tolerances for hot-rolled shapes dictated by ASTM A-6, which allows significant flange tilt off-center flanges, and other dimensional inaccuracies. Equipment may be designed to overcome this, but it will add to the expense.

Cold saw set-ups cost in the neighborhood of \$250-500k depending on the amount of material handling equipment. In this case, they are almost always configured with some conveying equipment and the demands of material handling specific to tees may alter this cost range.

Blades are the major consumables for cold sawing, although they may be resharpened several times. Cutting fluid is next in importance, especially considering the impact of increasingly stringent environmental regulations. Chips produced in the process are recyclable, but may require special handling due to the presence of the fluids.

Cold sawing can handle the entire range of thicknesses required but like all processes, cutting speed is a function of the thickness to be cut.

Abrasive Water Jet Cutting (AWJC)<sup>18</sup> has been used to cut many "problem" materials with great accuracy, from very brittle ceramics and metals to foam products. For I-beam stripping, the low heat input would produce little distortion but slow production rates and high installation and maintenance costs make it economically unfeasible. The process can cut at speeds up to 150 mm/min (6 ipm) on soft materials or light gauges of metals. Cutting rates drop to below 25 mm/min (1 ipm) on 25 mm (1-in) thick steel.

Equipment including pumps, intensifiers, distribution systems and manipulators can cost up to \$500K. Since pressures up to 50,000 psi are used wear is significant and maintenance costs are high.

Water and abrasive grit (typically garnet) are the major expendables. Although garnet is not a particularly hazardous material, it forms a sludge with the cut metal particles in the water tables. This is not recyclable because of the metal content and incurs a fairly high disposal cost.

AWJC is flexible in that it can cut a wide range of materials, but application of the process is limited due

to its low travel speeds. Excellent cut surface quality is produced by AWJC, and distortion to parts is minimal.

Arc Sawing<sup>19</sup> is a recently-developed technology that uses a spinning metal disc, or blade, which transfers current from its edge to the work piece. Extremely high currents, several thousand amperes, are **used, and incredibly high cutting speeds are possible.** The equipment runs completely submerged in water, and all current installations of this equipment are being used to cut decommissioned nuclear reactor vessels, limiting the amount of experimentation which might be carried out at existing installations. Little work has been done to establish the applicability of this equipment in other environments, however, the manufacturer reported a test in which an 203mm (8 in) diameter high nickel alloy (625) round bar was transversely cut to compare with the use of abrasive cut-off saws. The abrasive saw took 10 minutes to make the cut while the arc saw severed the bar in 8 seconds. Quality of the cut face was not as good as that produced by the abrasive method and no development work was ever undertaken to determine if edge quality might be improved.

Based on work done on flat plate, speeds are estimated to be nearly 9m/min (30 fpm) on 4.7mm (3/16 in) material, dropping down to 1.5m/min (5 fpm) on 25mm (1 in) thick steel.

This equipment would cost upwards of \$750k not counting any material conveying systems. Handling equipment would have to be capable of coping with the high electrical currents involved.

Electrical power (6,000 Amperes per head) is the primary consumable, but blade usage is a significant factor. Blades cost \$250 each and blade life is estimated at 150-300m (500-1,000 ft) of cut. At best for 16m (49 ft) long I-beams, each pair of blades would wear out after 20 cuts, thus deflanging 1700 beams would consume 170 blades at a cost of \$42,500.

It is not known how the geometry of I-beams would affect cutting properties and cut-edge quality. In contrast with heavy, flat plate cutting, I-beams present a non-uniform cross-section (see Figure 6.) to the blade. When high currents travel through non-symmetrical paths, magnetic flux from the current interacts with the magnetic flux of the arc, causing a phenomenon called "arc blow." Arc blow is often seen in welding at high currents, and appears as erratic arc action resulting in poor quality.

## Welding Methods

Welding processes reviewed are summarized in Table III. More traditional welding methods such as Gas

Table III. Welding Methods

Process	speed	cost	consumables	Flexibility	Quality
GMAW/FCAW	0.6-1.8m/min (2-6 fpm)	Med	Wire, Gas, Power	High	Exc
GMAW-P	0.6-3m/min (2-10 fpm)	Med/High	Wire, Gas, Power	High	Exc
SAW	0.6-2m/min (2-7 fpm)	Med/High	Wire, Flux Power	High	Exc
LBW	0.9-3m/min (3-10 fpm)	High	Wire, Power	Meal/High	Exc
HFRW	-60m/min (200 fpm]	H i g h	Power, Coolant"	Low	Exc

Metal Arc Welding (GMAW), Flux-cored Arc Welding (FCAW) and Submerged Arc Welding (SAW) are well documented and have an established range of typical procedures, thus discussion is purposely limited. Although some work has been done with pulsed gas metal arc welding (GMAW-P) for high speed applications, both that method and the field of Laser Beam Welding (LBW) are relatively untried in this form of manufacturing: i.e. long, heavy sections with high production volume. Figure 8 shows estimated welding speeds for GMAW (FCAW is nearly the same), SAW, and LBW. Speeds for GMAW and SAW are based on fillet welding to achieve 100% efficient welds (weld strength equals base metal strength). LBW speeds are based on achieving full penetration welds (50+% penetration from each side)<sup>24</sup>

Gas Metal Arc and Flux Cored Arc Welding (GMAW/FCAW)<sup>20</sup> have been widely used to produce fillet welds with mechanized equipment. Flexibility and quality are outstanding and equipment is relatively inexpensive, reliable, and readily available. Travel speeds will vary with the size of the weld required and will largely depend on the deposition rate of the electrode and welding parameters chosen. A new variation of the process is the use of "Metal-cored" electrodes, which have been seen to offer higher productivity with excellent arc stability and weld cosmetics. Major consumables are welding filler metal, which generally costs on the order of \$2.20/kg (\$1.00/lb), and shielding gas.

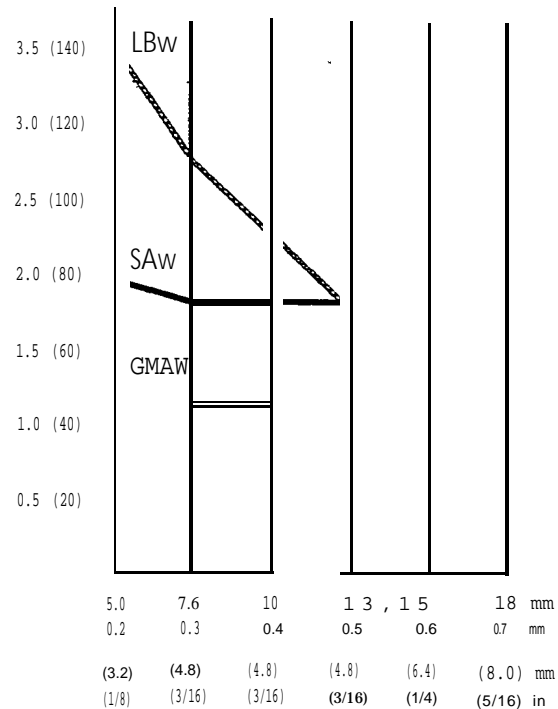
Pulsed Gas Metal Arc Welding (GMAW-P), uses very specialized pulsed power supplies to achieve extremely high speeds 3-4.5m/min (120-180 ipm).<sup>21,22,23</sup>

In general, weld sizes at these speeds have been small, and base plates fairly thin, so it is not known if this approach will provide the flexibility to perform large-scale welding of ship-sized structural elements, especially in the commercial arena. Costs of the consumables are the same as above, but the equipment is not widely available, and is more expensive than

traditional GMAW power sources. These speeds are competitive with those achieved by high power lasers, and double those offered by submerged arc welding.

Submerged Arc Welding (SAW) has been used to produce more fabricated tee shapes than any other welding method. The process is well understood, and although equipment is generally more expensive than GMAW/FCAW setups, it is still reasonably priced. The process offers good flexibility and generally faster travel

Welding Speed m/min (ipm)



LBW, Web Material Thickness  
(GMAW, SAW, Fillet Leg Size)

Figure 8. Welding Speeds for LBW, SAW, & GMAW

speeds than “open-arc” methods, especially for large welds, through the use of multiple wires. Other advantages of SAW are the low level of smoke produced and the lack of significant arc radiation, although these are not major considerations for highly mechanized equipment. Higher travel speeds result in reduced distortion although straightening by some means is required. This is often done in-process, by an in-line heating torch applying balancing heat to the opposite edge of the web. Major consumables for SAW are filler metal and flux and are similar in overall cost to those required for GMAW and FCAW. SAW can produce welds with excellent soundness and metallurgical properties.

Laser Beam Welding (LBW),<sup>24,25</sup> has grown in use in the last decade, producing high-quality, high speed welds with low distortion on a wide variety of materials. The fundamental disadvantage of the process is high equipment cost, but prices may drop as systems become more widely used. The cost of devices with power levels sufficient for fast processing of thicker parts has some impact on consideration of lasers for commercial ship work.

In fabricating tees, one significant fact associated with laser welding as opposed to cutting is that penetration by one beam through the entire thickness is not needed. Two opposing beams need only produce as much penetration as the design requires, something more than 50% if full penetration is required. One high power laser may cost more than double the price of two devices of half that power.

Laser systems can cost from \$300K to \$3,000k, but high-powered devices can make effective use of beam splitters, increasing the number of welds which can be made simultaneously. Thus, timer material could be processed in multiple parallel operations, or the system re-configured for single processing of thicker work pieces. Careful review of the whole production scenario is required.

Laser welding at speeds over 4m/min (160 ipm) is possible for thinner (<4.7mm (3/16 in)) sections included in this analysis. Travel speeds drop off for materials over 12.7 mm (1/2 in), especially with lower powered devices, but power level is not the only criterion for evaluating lasers. Beam quality, spot size, and brightness, can have bearing on an application.

Electrical power is a major consumable. Plasma suppression gas (helium) is usually used and it is expected that some filler metal would be needed to provide an acceptable weld profile.

Laser welding should yield the lowest overall distortion in as-welded parts, due to its very high energy density and fast welding speeds.

High Frequency Resistance Welding (HFRW) has produced large amounts of lightweight I-beams for truck trailers and mobile homes.<sup>6,7,31</sup> High current at high frequency is passed between web and flange connections, heating the junction quickly to forging temperature. Pressure rollers force the parts together for full-penetration welds. Machinery is large and expensive (costing millions of dollars), and suited to production of high quantities identical shapes, but runs at extremely high speeds, up to 61m/min (200 fpm). The method is generally used on lighter materials (9.5mm (3/8 in) and less), and works best with coiled strip, handled by unloaders and on-the-fly coil splicing stations. HFRW was recently used for producing several lightweight (8.92kg/m (6#/ft) and lighter) sections for later-flight CG-47 class vessels, and should be considered when large quantities of light weight sections are needed. HFRW is not able to process the full range of thicknesses of the DDG group of stiffeners.

## COST ANALYSIS

To determine a baseline cost for producing the target population of I/T shapes, the literature was searched for prior work relating to industry experience in I-beam stripping. To validate this information a time study of beam deflanging using the OFC process was made.

Conducted fourteen years ago under funding by the NSRP, the Semi-Automatic Beam Line (SABL) Feasibility Study included a limited review of the cost of I-beam deflanging. The SABL study compared the productivity of “standard” methods, measured at a shipyard to that of a proposed highly mechanized facility for all processing of structural shapes, including web frame fabrication angle and channel processing, end cuts, copes and bevels. The proposed Semi-Automatic Beam Line consisted entirely of improvements to conveying and material handling equipment. AU cutting including beam deflanging was done by the OFC process. There was no proposal to change the processing technology or process parameters used in any of the “standard” methods, and the substitution of fabricated tees for stripped I-beams was not suggested. The SABL study did not go into specific details for any of the functions, naming only two cost elements, “handling” and “processing.” Furthermore, the study did not look beyond the boundaries of the processing facility. The issue of material transport into and out of storage was tacitly treated as a constant. Handling referred to movement of material within the facility only, and handling functions were not reported or compared in any detail.

Finally, neither overall product quality nor rework were mentioned in the SABL study.

The SABL study did provide basic cost data associated with using the OFC process for deflanging 5,000 I-beams per year. Using the SABL study data as a base-line, this project analyzed I-beam stripping functions in greater detail, to verify that the current cost of deflanging by the OFC process was similar to the cost of the “Standard” method reported by the SABL study, and to evaluate areas where process improvements might have the greatest benefits.

Figure 9 shows this primary comparison the “Standard” method referred to in the SABL study (OFC deflanging of batches of I-beams) required approximately 1.3 labor hours (Lhrs) to strip flanges from one I-beam. The “Std verified” data (current practice reviewed in this report) showed a similar time per beam, when all in-process handling (rigging on and off burning tables, set-up, and scrap removal) was added to the actual OFC burning time under “processing.” “Handling” for the standard and the SABL comparison referred to the time spent on moving material to and from the process, within the facility. This was documented at 0.286 Lhrs per beam for the standard method and less than 0.2 Lhrs for the SABL method. For the verified standard data “handling” referred to movement of material from storage areas to the facility (approximately 0.57 Lhrs per beam).

While the SABL study concluded that handling and processing times could be substantially reduced, it is significant to note that the ratio of handling time to cutting time did not change (Figure 10). Although handling (as treated by the SABL study) was reduced by 40% (from 0.286 down to 0.171 Lhrs), it remained 18% of the total cost of producing I/T shapes.

Since the SABL methodology did not propose to change operating parameters of the OFC process, the total time for burning flanges from the 5,000 I-beams should be the same for both “Standard” and SABL. The reduction of 41% in processing cost (from 1.35 down to 0.8 Lhrs/part was not identified as the result of changes to OFC process parameters. Thus, the ratio of processing to handling time should not be equal, unless some time-related process elements, such as setting up and scrap removal, (which are really handling functions), were also included in “processing” by the SABL study.

Since any comparison of the relative cost of the various new alternatives should include the entire range of functions, it is necessary to break down the verified data into greater detail and include information about the amount of rework, as shown in Figure 11 Rework consists primarily of straightening, but includes a lower percentage of labor to repair damage to tees if the cut

has come too close to the web. Straightening is driven by an internal standard which allows maximum camber equal to half that allowed by ASTM A-6 for tees. Since the tees are substantially stiffer than the plates to which they are joined camber must be kept to a minimum to allow ship units to be accurately built. A-6 specifies allowable camber for tee sections solely as a function of length and 15.2m (50 ft) tees are allowed 31.7mm (1.25 in) maximum. Since structural shapes are supplied to ASTM A-6 requirements, it has been used as a convenient starting point especially when deflanging of tees has been subcontracted. The current internal standard was based on the experience that all subsequent phases of ship structure fabrication proceed more quickly when straighter tees are provided. The decision as to the output tolerance of the processing system can change the rework percentage greatly. If the A-6 guidelines were followed exactly, only 10% of the parts would need straightening. At a tolerance of one-half of the ASTM allowed value, 50% of parts produced by OFC typically will need straightening.

As a comparison to the standard and verified batch-mode OFC stripping, Figure 12 shows a percentage breakdown of the labor in continuous submerged arc welding<sup>28</sup>. Rework is not added since experience has shown that this equipment can consistently produce accurate tee sections.

#### Projected Costs

To provide a cost comparison of fabricating to stripping, seven different hypothetical production scenarios were generated. Four approaches to I-beam deflanging were compared to three welding scenarios.

I-beam stripping concepts evaluated were the standard oxyfuel cutting (Std-OFC) practice, re-equipping OFC batch-processing gantries with plasma-arc cutting capability (Batch-PAC), continuous-processing plasma-arc cutting (Contin-PAC), and continuous processing laser beam cutting (Contin-LBC). Cutting speeds for these methods were arrived at by estimating the thickness to be cut as the flange thickness plus one-half the radius of the transition of flange to web (Figure 6). This yielded a range of 7.62mm (0.30 in) to nearly 25.4mm (1.0 in) for tees used in the DDG-51. Manufacturers’ data and other published information were consulted to estimate cutting speed for each thickness, as shown in Figure 7.

Three welding scenarios were all considered as continuous-processing tee fabricating machines: submerged arc welding (SAW), gas metal arc welding (GMAW), and laser beam welding (LBW). Equipment manufacturers and other sources were consulted for performance data shown in Figure 8.

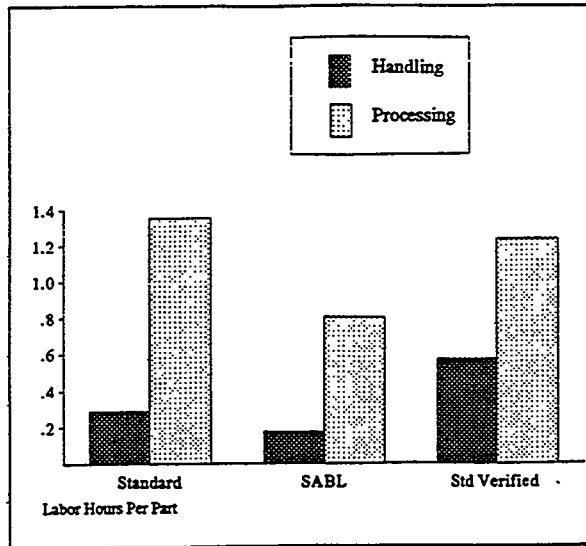


Figure 9. Verification of SABL Study Data

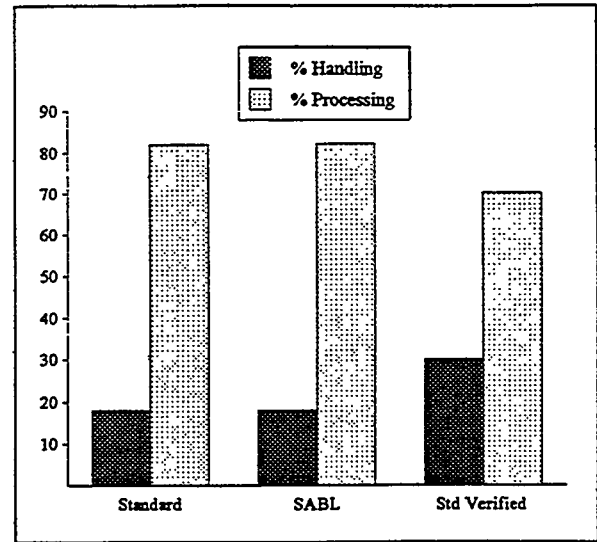


Figure 10. Relative Percentage of Cost Elements

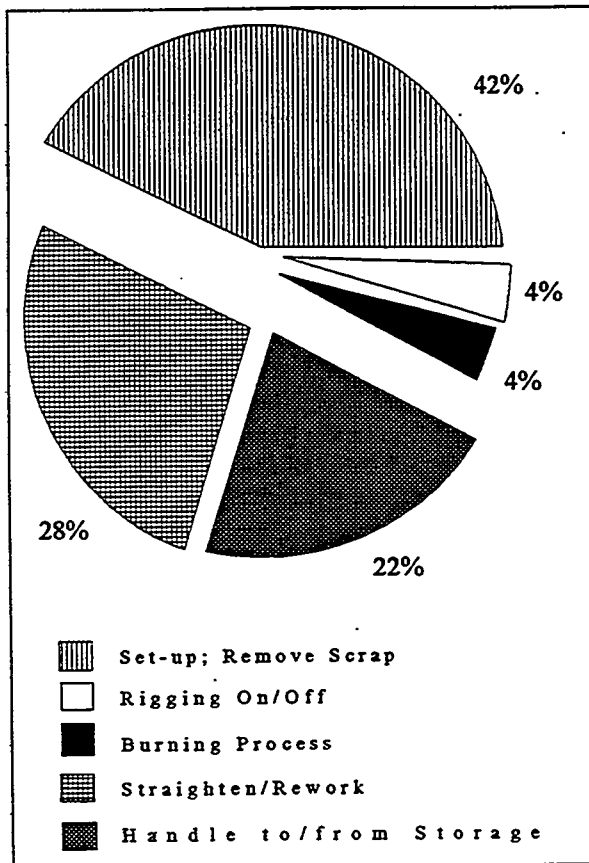


Figure 11. Functions in Batch OFC

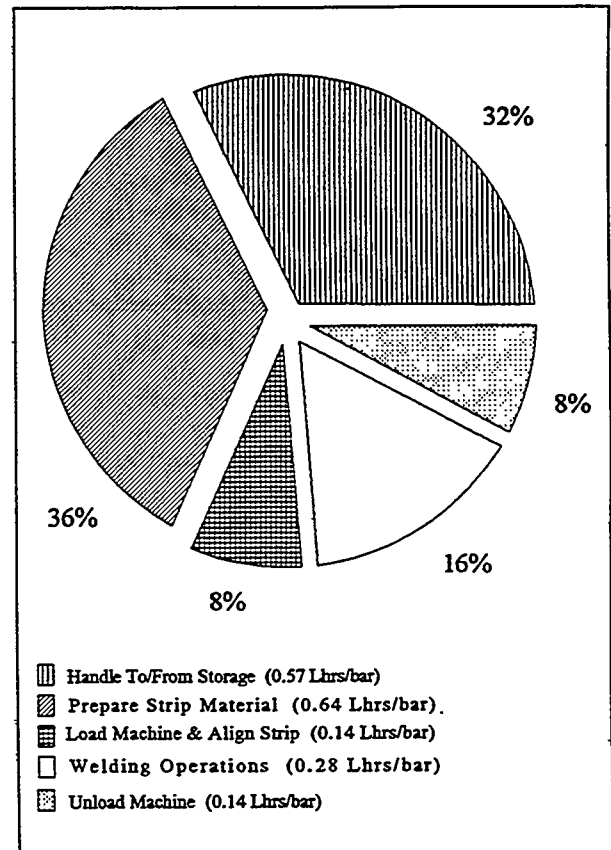


Figure 12. Functions in Continuous SAW

In most cases, for other than laser and plasma processes, these values are well documented and easily verified by virtue of many successful applications. The use of PAC, LBC and LBW in applications of the indicated thickness range and particular geometry has not been reported so that estimates of expected rates have been made based on available literature.

A number of baseline criteria were established.

1 Capital cost of the equipment was not considered.

. Final costs were the summation of production costs, including handling times.

1 Cutting speeds were based on thickness of the flanges plus half the radius of transition from web to flange.

1 Required weld size was based on the thicknesses to be joined, and full penetration welds were not assumed except for the case of laser welding, which also assumed small-sized reinforcing fillets.

1 Based on experience, rework was not factored into the welding scenarios.

1 Cutting methods had rework added in at the experienced rate of the verified data for standard OFC, and half that for the other cutting methods.

- **A** standard rate of 4 labor hours per plate was used to calculate processing time to produce strips for tees from plates. The total of flange and web widths plus kerf was used to estimate the number of plates required and the scrap generated in this step.

Based on these assumptions, a production cost sensitivity analysis was generated comparing labor cost, material cost and machine utilization variations as major elements in overall cost. Labor rate was factored in steps from \$15/hr to \$40/hr. Material costs were figured from \$0.08/kg (\$0.18/lb) to \$0.136/kg (\$0.30/lb). Steel cost was treated as the same for both plate and shapes. The price of plates and shapes can vary widely depending on factors such as quantity, lead time, and market demand, to name only a few. With a competitive steel market and the recent emergence of mini-mills, there is pressure on major steel producers to control costs.

In assessing the effect of varying duty cycle, for batch processes, the experienced standard data was used throughout so the lines for Std-OFC and Batch-PAC are constant. Since any machine is profitable only when it is used however, duty cycles from 50% to 95% were calculated for the continuous-process implementations. Considering that a tee fabricating machine usually only requires a 15-second delay between finishing one section and starting the next the 95% maximum was somewhat conservative<sup>28</sup>.

As a further attempt to consider these scenarios on a reasonably equal footing, the travel speeds of oxyfuel cutting were based on manufacturer's charts, nearly two feet per minute in most cases, and were substantially higher than those used in current production. Since the burning time in the current process amounts to only 4% of the total labor per piece, there is no substantial reduction in overall costs from the calculated increase in speed.

Once this data was entered time required to produce the target group of tees was generated, and labor cost, material cost and machine utilization variations were varied to yield several overall cost. Tables IV, V, and VI show the detailed results of the time and cost comparisons, and Figures 13, 14, and 15 provide the information in graphical form.

This analysis yields these conclusions.

1 In every case, the overall cost to fabricate was lower than the cost to ship, frequently by as much as 30%.

1 The reason for the large difference is the loss of 25% of purchased material as scrap in the cutting operations.

1 Even if processing scrap is not considered fabricating methods are still lower in cost.

1 Laser processes show the lowest cost in each review, but there is little practical experience to back up the performance estimates.

1 Of the traditional processes, submerged arc welding shows the lowest overall cost in each scenario, thus it is not surprising that this process has the greatest industry experience in the fabrication of tee sections.

The chart shown in Figure 16 summarizes these conclusions. Batch-type oxyfuel cutting and continuous submerged arc welding processes have a considerable experience base throughout the industry. The laser processes, whether cutting or welding, have not been used for work in this manner, so the data is predictive, and may not be realized in production. Additionally, lasers cost orders of magnitude more than SAW or OFC equipment and since capital costs have not been included this may skew the results depending on the expected life span, maintenance, and other costs associated with laser equipment.

Further, material is the dominating cost for all the methods, and reduction of scrap is a major factor in the savings. Total material cost for the shipped product is very nearly equal to the total cost of the fabricated tee. Considering strictly labor, the greatest potential of the continuous methods is the reduction in set-up and handling labor. Even without rework total cost for deflanging still exceeds that of fabricating.

Table IV. Processing Cost (x\$1000) vs. Labor Rate (@ \$.22/lb and 95% Duty Cycle)						
	Labor Rates, \$/hr					
	15	20	25	30	35	40
Std OFC	404	425	446	467	488	510
Batch PAC	394	411	429	447	464	482
Contin PAC	377	390	402	415	427	440
Contin LBC	369	379	389	399	409	418
Contin SAW	280	296	311	326	342	357
Contin GMAW	289	308	325	344	362	381
Contin LBW	276	289	303	317	331	344

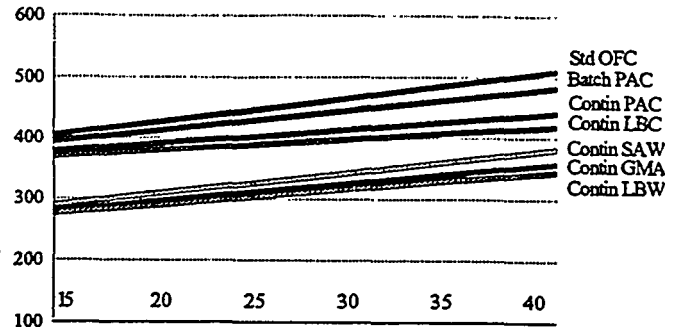


Figure 13. Processing Cost (x\$1000) vs. Labor Rate (\$/hr)

Table V. Processing Cost (x\$1000) vs. Steel Cost (@ \$35/hr and 95% Duty Cycle)								
	\$ /kg	Steel Cost						
		0.4	0.44	0.48	0.53	0.57	0.62	0.66
	\$ /lb	0.18	0.2	0.22	0.24	0.26	0.28	0.3
Std OFC		427	457	488	519	550	581	612
Batch PAC		403	434	464	496	527	558	589
Contin PAC		365	396	427	458	484	520	551
Contin LBC		347	378	409	440	470	501	532
Contin SAW		299	320	342	363	384	406	427
Contin GMAW		320	341	362	384	405	426	448
Contin LBW		288	309	331	352	373	395	416

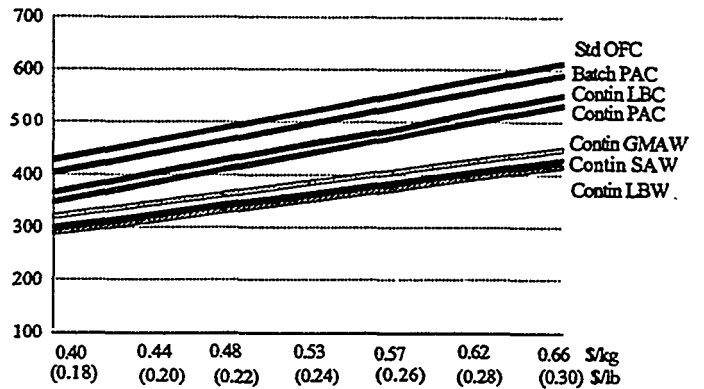


Figure 14. Processing Cost (x\$1000) vs. Steel Price

Table VI. Processing Cost (x\$1000) vs. Machine Duty Cycle (@ \$0.49\$/kg (\$0.22/lb) and \$35/hr)							
	Machine Duty Cycle						
	0.5	0.6	0.75	0.8	0.85	0.9	0.95
Std OFC	488	488	488	488	488	488	488
Batch PAC	465	465	465	465	465	465	465
Contin PAC	460	448	437	434	431	429	427
Contin LBC	424	419	413	412	411	410	409
Contin SAW	372	361	350	348	346	344	342
Contin GMAW	411	394	377	373	368	365	362
Contin LBW	351	344	337	335	333	332	331

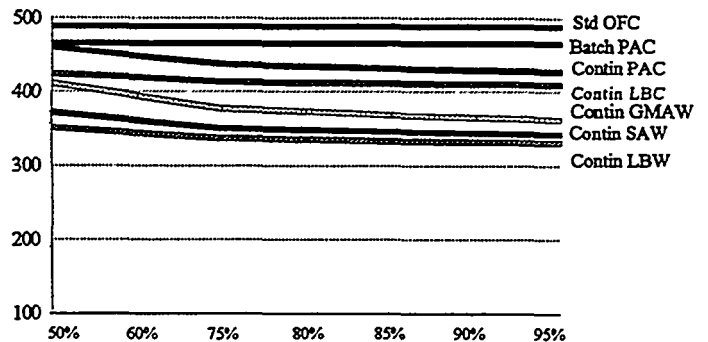


Figure 15. Processing Cost(x\$1000) vs % Duty Cycle

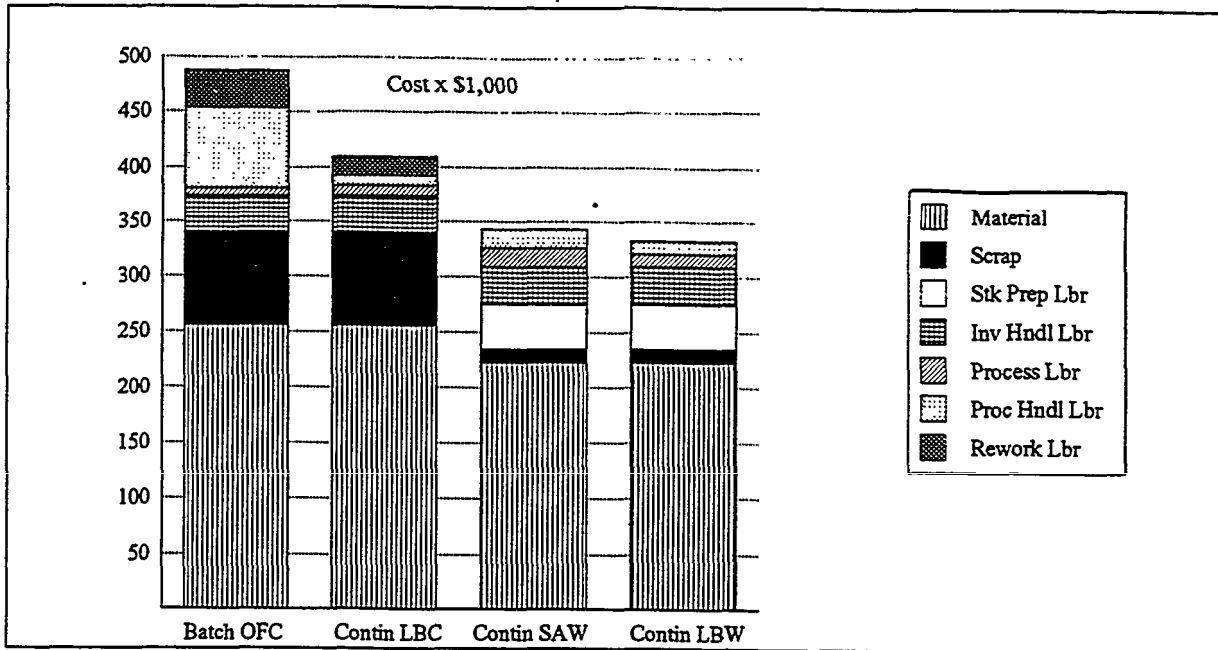


Figure 16. Cost of Batch OFC vs. Continuous LBC, SAW, & LBW

## MOCK-UP TESTS

Where appropriate equipment was available, mock-up tests were conducted to test methods for this review. Processing speed and cut quality were evaluate and distortion induced by the process was measured when possible. In many cases, existing equipment was not configured to do a close approximation of a stripping cut or to make tee-section welds. In most cases, only one cutting head or welding head was available, so the stripping or welding operation was done in two sequential operations. This provided some degree of judgment about how the process might perform if adapted to the task of producing tee shapes, although the effect of two simultaneous cuts or welds could not be fully proved. small-scale mockups were used to establish parameters for a given speed and quality, and large scale mockups were used to evaluate distortion. The ability to do large parts was limited. Abrasive water jet cutting was evaluated to determine if beams deflanged by a non-thermal process would show distortion due to the release of residual stresses which might be present after hot-rolling.

To provide a standard section for cutting tests, wide-flange beams, W6X20#, were used. This I-beam has a flange thickness of 9.5 mm (3/8 in), and a radius transition from web to flange of 7.62mm (0.30 in), which is in the mid-range of weight and thickness of the target group. These were cut to the maximum

length possible for processing at the given facility. Most test pieces were only 600mm (2 ft) long, but a few 2.4m (8 ft) pieces were cut. Laser tests were made using lasers of as many different types as possible.

Since the traditional welding processes are well document, only two welding tests were performed. Using a CO<sub>2</sub> laser, two tees. were produced one welded with filler metal, and one welded autogenously (no filler metal added). The tee shape was approximated by using 9.5x152mm (3/8x6 in) flat bars for both web and flange. Since the 6x20# I-beam has a 6.3mm (1/4 in) web, this using thicker material was somewhat conservative, requiring greater weld penetration.

The mock-up tests are documented in greater detail in the NSRP project report, which includes appropriate photographs of the test pieces.

The following small-scale mock-up cutting tests were performed

- 1 Laser cutting of 600mm (2 ft) sections at Applied Research Laboratory, PennState University, using 2.4kW YAG and 1.5 kW CO<sub>2</sub> lasers,
- 1 Laser cutting of 2.4m (8 ft) sections at ARL using the 14 kW CO<sub>2</sub> laser;
- 1 Laser cutting of 600mm (2ft) sections using the kW GE Fanuc CO<sub>2</sub> laser at Edison Welding Institute;
- 1 Laser cutting of 600mm (2 ft) sections using a 3 kW YAG laser at Hobart Laser Products;

Abrasive water jet cutting of an 2.4m (8 ft) section at Laser Applications Inc.; and



1 Oxy-fuel cutting of 2.4m (8 ft) sections at Bath Iron Works.

The following large-scale mock-up cutting tests were performed

- 1 Oxyfuel cutting of 12.2m (40 ft) sections at Bath Iron Works, and
- 1 Plasma-arc -cutting of 12.2m (40 ft) sections at Bath Iron Works.

The following large scale welding test was performed

- Laser welding of 6.1m (20 ft) sections using the 25 kW CO<sub>2</sub> laser at Sturdyne, Inc.

#### Summary of Mock-up Tests

For most laser and plasma cuts, edge quality was nearly as good as that attained with oxyfuel processes, and for most cases, higher travel speeds were noted than those used for traditional burning.

In general, the processes tested performed at speeds lower than originally estimated. Typically, this was due to the difficulty of estimating cutting performance radius at the flange to web transition.

Abrasive water jet cutting produced no measurable distortion in a 2.4m (8 ft) but these pieces were too short to evaluate distortion with any process.

PAC of 12.2m (40 ft) sections resulted in approximately half the distortion produced by OFC.

For both OFC and PAC, water sprayed on the parts being cut will reduce distortion by nearly 50%.

Autogenous laser welds in 6.1m (20 ft) parts produced little distortion when filler metal was added to provide fillet reinforcement < distortion increased.

Distortion measurements taken are summarized in Table VII. The use of 2.4m (8 ft) sections did not provide enough length to gain much insight into potential distortion which might be produced by laser cutting. The oxyfuel result for 2.4m (8 ft) parts is contradictory, but the numbers are so small that it is difficult to draw a valid conclusion.

Water spray is a useful method for reducing distortion. A trickling stream from a small nozzle positioned immediately behind the cutting head gave a better than 50% reduction in camber for both the plasma and oxyfuel processes.

#### CONCLUSIONS

Scrap material from the deflanging process averages 25% of material purchased. Table I. shows that the deflanging operation generates 172 tonnes (170 long tons) of scrap with the amount of scrap per item varying from 20% to more than 30%. At \$0.53\$/kg (\$0.24/lb), this is a loss in excess of \$90,000.

Processing costs for fabricating tees are generally lower than for stripping I-beams. Welding methods and machinery can operate at higher speeds and duty cycles than traditional batch-type oxyfuel stripping gantries. Also, in the fabricating operation the production of web and flange strips results in scrap on the order of only 5% by weight of purchased material hence there is a large reduction in material cost when fabricating is compared to stripping.

Handling is a major cost driver for both fabricating and stripping Operations. Material handling within the shipyard to support tee stripping can amount to more than 70% of labor cost. Thus any increase in cutting process speed may drop overall costs only slightly. In stripping, one piece is brought into the facility, and three pieces must be removed, only one of

Table VII. Distortion Measurements

Process	Measured Camber mm (inches)				
	2.4m (8ft) Dry	2.4m (8ft) Water	12.2m (40ft) Dry	12.2m (40ft) Water	6.1m (20ft) Welded
AWJC, single cut		0			
LBC (14 kW CO <sub>2</sub> single cut	1.5 (1/16)				
OFC, single cuts	0.8 (1/32)	1.5 (1/16)			
OFC, double cuts	3.2 (1/8)	3.2 (1/8)	118 (4-21/32)	55.5 (2-3/16)	
PAC, double cuts			70 (2-3/4)	30 (1-3/16)	
LBW, autogenous					4 (5/32)
LBW, with filler metal					14.3 (9/16)

them a useful product. When tees are fabricated however, two pieces are brought in and only one is removed. Most tee fabricating machinery is highly mechanized to reduce handling, and conveyor systems are a major part of the capital cost of such equipment.

Continuous-process machines can offer significant cost reductions over batch-type methods. Due to more efficient in-process handling, costs are lower even though four operators may be required (batch-type oxyfuel typically requires two). Large tee beam fabricating machines align parts accurately, and provide in-process straightening, resulting in minimal rework.

The plasma-arc cutting process produces less distortion than the oxyfuel method. Test beams (12.2m (40 ft) long) stripped using PAC showed camber to be reduced by 50%, compared to beams cut by the oxyfuel process.

A light water spray reduces camber distortion significantly. On the 12.2m (40 ft) test beams, for both oxyfuel and plasma arc processes, a trickling stream of water directed immediately behind the cut reduced final camber by 50%, compared to beams cut without added water spray.

Capital and maintenance were not included in this cost analysis and could have significant affect on any decision as to overall processing strategy. Since the capital acquisition cost will depend on the work mix and specific conditions of individual sites, this analysis focused on operational cost of processes only.

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## Producibility of Double Hull Tankers

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### ABSTRACT

Alternative structural system concepts have been developed for 40K and 95KDWT double hull tankers, with the objective of studying their producibility in existing U.S. shipyards, including labor hours and construction schedules. Structural components and elements considered included alternative material, shell plating, bulkheads, stiffeners and other structural elements for both conventional and unidirectional double hull tankers, together with shipbuilding processes such as automation and accuracy control, and standardization including design. It is concluded that increased automation, accuracy control and standardization are the areas where the greatest gains may be possible to make U.S. shipyards more productive and more competitive on a world scale.

### INTRODUCTION

It is generally acknowledged that the labor hours of constructing commercial ships in U.S. shipyards is higher than foreign shipyards, particularly those in the Far East, Southern Europe and Brazil. There are other significant differences of a technical nature which will have a substantial impact, including labor hour requirements for design and construction, materials, equipment and machinery lead time, shipbuilding practices and facilities, use of standards, contractual processes, and institutional constraints.

During the past twenty years, U.S. shipyards, various agencies of the government and the Society of Naval Architects and Marine Engineers (SNAME) have tried to address the matter and improve producibility. U.S. shipyards have acknowledged the advancement of Japanese shipbuilding techniques and, together with the U.S. Maritime Administration (MARAD), have imported technology from innovators like IHI Marine Technology, Inc. (IHI), who has transferred information to Bath Iron Works Corporation, Newport News Shipbuilding, Ingalls Shipbuilding, Avondale Shipyards, National Steel and Shipbuilding Company

(NASSCO) and others. MARAD and later SNAME have sponsored the National Shipbuilding Research Program (NSRP) (now Under SNAME sponsorship with U.S. Navy funding), which supports extensive and varied research in shipbuilding technology from design through delivery. However, a significant gap still **appears to be present between the U.S. and the major world shipbuilders.**

The time required for the construction of a vessel has been identified as having a major impact on vessel labor hours. Reported delivery times in foreign shipyards are considerably less than U.S. shipyards. The reasons for this must be largely tied to the nature of the structure being manufactured and to the degree it facilitates installation of outfit and much of the painting prior to erection on the building berths. The design phase and its integration with construction has a significant influence on achieving this goal. These matters, which are in the shipbuilder's control, are addressed herein.

It is acknowledged that the world's aging tanker fleet must be replaced in the years to come. This will provide a significant opportunity to revitalize shipbuilding in the U.S. Furthermore, the passage of OPA '90 has resulted in new requirements for tankers, specifically double hulls, and this allows significant latitude for the development of designs with innovative enhancements for producibility. These could give the developer a significant advantage over the competition.

The objective of this project was to "develop alternative structural system concepts" for 40,000 (i.e. 40K) and 100K deadweight tons (KDWT) (reduced to 95KDWT later) Jones Act double hull tankers for construction in existing U.S. shipyard facilities. These should result in decreased labor requirements in the design, instruction, and outfitting phases of the shipbuilding program as well as providing for low cost maintenance during the life of the vessels. It is hoped that addressing this type and these sizes of vessels will provide information to shipbuilders which will be useful in identifying improvements necessary for competing in the upcoming boom for rebuilding the world tanker

fleet.

The objective of the project was approached by the plan identified by Daidola [1]<sup>1</sup> under contract to the U.S. Coast Guard on behalf of the Ship Structure committee [2].

## SHIPYARD FACILITY CONSIDERATIONS

Table I depicts what is considered to be an existing U.S. shipyard, that is, one that would be capable and interested in competing in the world commercial ship market (adopted and modified from [3]). Table II depicts a notional shipyard, which may be considered typical of a modern foreign shipyard.

The study described herein is concerned with existing U.S. shipyards without significant facilities enhancements. Consequently, the data contained in Table II is presented for informational and comparison purposes only.

## INSTITUTIONAL CONSTRAINTS

The burden of institutional constraints, in the form of the added cost of compliance with U.S. regulations in the marine industry, has often been cited as a significant contributor to the high cost of building commercial ships in the U.S. This subject was discussed in Reference [4], specifically with regard to the impact of U.S. Coast Guard (USCG) regulations. Some important points extracted from this reference are as follows:

U.S. shipbuilders have little choice, in many cases, but to purchase marine machinery and equipment from foreign vendors. According to a recent statement by the shipbuilders Council of America (SCA), foreign manufacturers of marine machinery charge premium prices, adding an average of 15% to the material costs of a U.S.-flag ship built in a U.S. shipyard, to cover the costs - real or perceived - of compliance with USCG design and inspection requirements for U.S. flag ships. The cause of this is the erosion of the U.S. supply base for marine equipment and material.

The American Commission on Shipbuilding, created by Congress through the Merchant Marine Act of 1970 in its "Report of the Commission on American Shipbuilding" cites an addition of 3-5% of the cost of a U.S.-flag vessel for compliance with the technical requirements of the Coast Guard, American Bureau of Shipping (ABS), and U.S. Public Health Service. Other added costs are cited which range from a low of 1% to a high of 9% of total vessel cost. These

differences in cost were largely attributed to implementation of the International Convention for the Safety of Life at Sea, 1974 (SOLAS 74) and its Amendments. The impact of this was particularly severe on the conversion of older ships built before SOLAS 74. However, it should be noted that SOLAS 74, as amended, and Other IMO requirements, have minimized the difference between design requirements in force worldwide and those in USCG regulations.

The cost of ABS classification has been cited as an "add on" cost; however, all commercial ships in foreign trade must be classed by a reputable classification society in order to obtain insurance, and the technical standards and Service charges of the leading Classification Societies are not all that different.

It is not clear whether all percentages quoted are based on total ship cost or the price the purchaser pays the shipyard for the ship, which may exclude sizeable foreign government subsidies.

While the percentage figures quoted vary widely, it appears that some small incremental cost of compliance with USCG regulations exists. The USCG is sensitive to this incremental cost and continues to make efforts to reduce the regulatory burden. In any case, a U.S. flag vessel built in a foreign shipyard or within the U.S. is required to comply with the same regulations. Therefore, the differences in cost and added time for approval may then be in favor of the vessel building in a U.S. yard.

- USCG regulations are not applicable to foreign flag ships even if built in U.S. yards. The absence, until recently, of foreign flag shipbuilding in the U.S. must be attributed to factors such as long delivery schedules and corresponding high costs at U.S. yards, not any "added" cost of compliance with USCG regulations.

## STRUCTURAL ELEMENTS

Structural elements are fundamental features of a structure, such as individual components, type of framing (longitudinal or transverse), flat versus curved plating, incorporation of structural standards, etc., or a production process such as plate forming, flame burning or welding.

Candidate structural elements which can be utilized in assembling alternative structural system concepts having the potential for improving the producibility of double hull tankers have been identified, including components, material, processes, shipyard facilities or design features, as shown in Table III.

<sup>1</sup>Numbers in brackets indicate Reference numbers.

**Table I: EXISTING U.S. SHIPYARD**

<ul style="list-style-type: none"> <li>○ Mid 1980 technology steel processing and fabrication shops, material handling and cranes. \$5 - 10 mil annual improv.</li> <li>○ Facilities           <ul style="list-style-type: none"> <li>- Plate stockyard</li> <li>- Shape stockyard</li> <li>- Plate treatment</li> <li>- Shape treatment</li> <li>- Plate processing shop</li> <li>- Shape processing shop</li> <li>- Panel line</li> <li>- Subassembly shop</li> <li>- Assembly shop</li> <li>- Shaped assembly shop</li> <li>- Block platens</li> <li>- Treatment and coating</li> <li>- Shop/platens to berth handling</li> <li>- Berths</li> <li>- Pipe shop</li> <li>- Equipment module shop</li> <li>- Outfitting quay</li> </ul> </li> <li>○ Equipment           <ul style="list-style-type: none"> <li>- Includes plate and shape pre-processing treatment</li> <li>- N/C burning machines, plate rolls and presses.</li> <li>- Line heating, frame bending by hydraulic machine. Panel line for flat stiffened panels. Welding. Subassemblies are processed in designated area and fed to both panel line and shaped structure shop. Pin jigs are used for shape structure. Some multi-wheeled transporters used.</li> <li>- Equipment and piping produced in outfit package shop.</li> <li>- Conveyors, overhead cranes in shops, panel and block transporters, outfit pallet trucks, platen cranes and berth cranes are all material handling.</li> </ul> </li> <li>○ Designated "On Block" outfitting before or after block coating treatment.           <ul style="list-style-type: none"> <li>- Deckhouse panels assembled in specialshop for "On Block" outfitting.</li> <li>- Joiner work done after completion of structure and outfitting.</li> </ul> </li> </ul>
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**Table II: NOTIONAL SHIPYARD**

<ul style="list-style-type: none"> <li>○ Equipment           <ul style="list-style-type: none"> <li>- Includes plate and shape pre- processing treatment w/ conveyor handling.</li> <li>- Line heating, frame bending by hydraulic machine w/ computer templates or inverse lines. Panel line for flat stiffened panels w/ one side welding and automatic stiffener welding. Panels and shaped structure are joined to form 3 dimensional blocks at outside platens.</li> <li>- Equipment and piping produced in outfit package shop.</li> <li>- Submerged Plasma cutting/computer controlled.</li> <li>- Mechanized steel storage handling with remote identification and sensing.</li> <li>- Cranes with magnetic or pneumatic lift.</li> <li>- Automatic beam forming.</li> <li>- Computer fairing, straking, nesting and layout.</li> <li>- Modular scaffolding.</li> <li>- Self-traveling staging</li> <li>- Block or module turning gimbals.</li> <li>- Hydraulic block alignment systems.</li> </ul> </li> <li>○ Complete design, engineering and CAD. Design for production emphasized. Suitable documentation to suit structural block and zone outfitting.</li> <li>○ Welding           <ul style="list-style-type: none"> <li>- With Fluxcore Wires (FCW welding).</li> <li>- Welding robotics for the more difficult areas.</li> <li>- Laser Welding.</li> </ul> </li> <li>○ Process lanes.</li> <li>○ Statistical accuracy control.</li> </ul>
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**Table III: STRUCTURAL ELEMENTS**

Element	
1. Extra wide plating to reduce the number of welded seams.	3. High percentage of single curvature plate at forward and aft ends.
2. Tapered plating.	4. Reduced numbers of piece parts in structural assemblies.

5. Built up plate piece vs. single plate with cut-outs (e.g. lower wing tank web)
6. Corrugated or swedged plating - see Figure 1.
7. Rolled VS. built up Sections.
8. Fabricated stiffeners and girders (possibly of two strength materials) vs. rolled section.
9. Striugers - to facilitate construction and aid inspection.
10. Use of bilge brackets in lieu of longitudinals in the bilge turn area.
11. No longitudinal in bilge turn area and bilge brackets negated due to thicker shell plating.
12. Longitudinal girders without transverses.
13. standardized plate thicknesses in inventoxy. Establish limiting plate thickness to avoid weight gain from transition thickness plate.
14. standardized stiffener sizes in inventory.
15. standardized structurall details (good producibility and weldabiity together with low failure rate).
16. standardized equipment and foundations.
17. Coiled plate. Presumably in rolls and would be available in longer lengths.
18. Stiffened elements fashioned from one frame width of plate with stiffener formed on one side - see Figure 2.
19. Double bottom floors and girders lugged and slotted into bottom shell and inner bottom for easier alignment. Similar technique could be used in wing tanks and on double plate bulkheads etc. - see Figure 3.

#### Materials

Limit steel grades used to those which do not present problems with welding, fatigue due to less than optimum detailing, etc.

#### Processes

1. Robotic welding.
2. Robotic painting and paint touch-up.
3. Robotic inspection..
4. Numerically controlled frame cutting.
5. Line heating.
6. Standardized welding details.
7. standardized accuracy..
8. Standardize statistical analysis of structural accuracy variations.
9. Standardized modular/zone construction (interim products).
10. Lapped joints in low stress areas.
11. One sided welds.

#### Use of Shipyard Facilities

1. Optimize block size to suit shipyard transporter and crane capacities.
2. Optimize sturcture to suit shipyard panel line and other facilities.

#### Design Features

1. No dead rise, camber or sheer.
2. standardized stiffener spacing.
3. Standardized double skin separation (keep same in all size vessels if feasible).
4. Standardized aft end design - engine room, mooring etc.
5. standardized forward end design - mooring, anchoring etc.
6. standadized transition of double skin to single skin.
7. Formed hopper corner knuckle - see Figure 4.
8. Flat deckhouse sides and ends.
9. Standardize deck heights to minimize number of different heights.
10. standardize size and type Of closures, scuttles, and accesses to the smallest variation practicable.
11. Align and locate all sanitary spaces to simplify piping.
12. Collocate spaces of similar temperature charcterisitcs to minimize insulation requirements.
13. Locate access openings clear of erection joints to allow pre-installation of closures.
14. Provide specific material coating and equipment preferences and reasons for preferences i.e. types of pumps, pump locations, equipmentt makers, cattings, materials, cable types, cable trays, piping arrangements, valve types, valve locations; windlass arrangements, hose arrangements, etc..
15. Structurall trunks for cables and pipes (lower tween deck height is then possible).
16. Design risk and possible failure should be considered when proposrng new structural or outfit concepts.

#### Alternative Structural Concepts

1. Longitudinal framing with formed hopper side comer and corrugated bulkheads.
2. Unidirectional stiffening supporting inner and outer shells, Figure 5.
3. Dished plate unidirectional hull, wherein the added strength due to the curvature in the shell and other plating increases the resistance to deformation and buckling and therefore permits decreased thickness of plating for a given spacing of girders, Figure 6.

Table IV indicates those structural elements applicable to existing shipyards as set forth in Table I. Table V indicates those alternative elements applicable to a notional shipyard as set forth in Table II.

#### ALTERNATIVE STRUCTURAL SYSTEM CONCEPTS

In order to assemble the structural elements identified into alternative structural system concepts for a double skin tanker, they were first grouped into categories associated with the components of the structural, machinery and outfitting systems, as shown in Table VI.

In order to maintain a manageable number of alternatives and facilitate an objective producibility comparison, some elements and components had to be selectively considered on a subjective basis.

As a result, a series of alternative structural system concepts have been synthesized from the components and elements shown in Table VI. Each alternative consists of 24 components or elements generically depicted in Table VII. As can be seen, of the 24 components or elements, eleven are directly varied, while the remainder are in accordance with baselines described in Reference [2].

#### APPLICATION TO SPECIFIC DOUBLE HULL TANKERS

The next step is the application of the alternative structural system concepts to Jones Act double hull tankers to investigate the potential for improved producibility in the U.S. A further objective is the estimation of baseline construction schedules and labor hours for construction of these vessels.

The sizes of tankers for application in this study were in the 40K to 100KDWT range. The Jones Act trade has made use of tankers of approximately 40KDWT over the years, although they have been rarer in the international market with vessels in the 30K+ and 54KDWT sizes being more prevalent. The 100KDWT size range tanker has also been used in the Jones Act Trade. Foreign vessels in this size range are generally just under 100KDWT and of the "Aframax" type.

As a result, the following procedure was adopted:  
1 A vessel resembling a 95KDWT 1993-95 vintage Far Eastern built crude carrier was adopted as the baseline vessel. The general arrangement and midship section are shown in Figures 7 and 8 respectively. The principal Characteristics are given in Table VIII.  
1 A foreign design example for the 40KDWT vessel was not available. Accordingly, a hybrid was prepared utilizing the generic features of the 95KDWT Far

Eastern vessel and principal characteristics indicated by previously built 40KDWT tankers for the U.S. Jones Act trade. The general arrangement and midship section are shown in Figures 7 and 9 respectively. The principal characteristics are given in Table VIII.

The unidirectional hulls have slightly different dimensions to suit assumed proportions of the structural cells in the double skin, as shown in Table IX, but cargo capacity is essentially the same as that of the baseline vessel.

#### BASELINE CONSTRUCTION SCHEDULES AND LABOR HOURS

Typical schedules of construction, distribution of labor hours as well as actual labor hours, were sought in the literature, from shipowner experiences and through foreign - shipyard contacts. Pertinent information was received from all sources on shipbuilding schedules and distribution of labor hours. However, virtually no current information on actual labor hours was obtained, presumably due to its proprietary nature.

Construction schedules have been identified from the sources noted above. Figure 10 shows examples for several types of vessels constructed in the U.S. and abroad, indicating months from start of fabrication to launch. Fabrication is defined as commencement of steel cutting.

Figure 11 indicates two schedules from contract to delivery for constructing double hull tankers. These schedules are for a Danish yard (84KDWT) [5] and a Japanese yard, [6]. Note that the total schedules from contract signing to delivery are 22 and 20 months respectively..

Table X shows a 1992 comparison [7] of labor hours and period required for delivery of the first 80KDWT tanker after contract for an average U.S. shipyard and a typical Japanese shipyard. It indicates that the U.S. is superior in outfit and piping construction, but inferior in design techniques, casting techniques and production control. Although the data compares an average U.S. shipyard and a typical Japanese shipyard, no justification is offered for the large differences in the numbers, nor is it clear if the values are applicable to 1992. As shown, the labor hours are 594,000 for the Japanese and 1,374,000 for the U.S. yard. (Note: the reference indicated the U.S. labor hours as 2,374,000, which is believed to be a typographical error.)

Table XI assesses the impact of technologically advanced shipbuilding techniques on labor hour requirements and shipbuilding cycle time, [8]. It is a comparison between an automated and a conventional yard in 1985, and indicates a 32% reduction in labor hours for the automated yard. In addition to labor hour



**Table IV: STRUCTURAL ELEMENTS  
APPLICABLE TO EXISTING U.S.  
SHIPYARDS**

- Rolled vs. built up sections.
- N/C hull penetrations.
- Line heating.
- Maximum block size to suit capability of shipyard facilities.
- Maximum length of blocks to suit steel availability.
- Reduced numbers of piece parts in structural assemblies.
- Rounded gunwale.
- Internal webs of upper wings and flopper from traditional web frames to plate webs.
- Ends of stiffeners for floors simplified for production.
- Cargo area revised to yield identical tanks and therefore identical blocks.
- Cautious approach to use of high strength steels.
- Coating applied environmentally in sheds, 60% done in sheds, 25% on outfitting pier, rest in dock. Blasting w/ steel and 80% re-usable copper grit.
- Pre-installation of access closures.

**Table V: STRUCTURAL ELEMENTS  
APPLICABLE TO A NOTIONAL  
SHIPYARD**

- Standardized accuracy.
- Standardized modular/zone construction (Interim products).
- One sided welds.
- Structure optimized for use with builder's process lanes and other facilities.
- Standardized size and type of closures to smallest variation practicable.
- Standardized design details.
- Single curvature longitudinals.
- Developable surfaces.
- Cheaper to change structure to make it more friendly to automation at a fraction of cost of robotics.
- Unidirectional vessel blocks are as long as practical considering crane capacity.
- Engine room block size to 300t.
- Deckhouse 60% outfitting done before lifting on board.
- Deck piping 80% done before lifted on board.
- Standard statistical analysis of structural accuracy variations.
- Robotic welding. (Note - see "cheaper" above)
- Robotic inspection.
- Robotic painting and touch up.

**Table VI: COMPONENTS AND ELEMENTS OF STRUCTURAL SYSTEMS**

<b>Hull Form</b>	<b>Tank Arrangement (in addition to double skin)</b>	<b>Shell</b>
Flat surfaces	No CL or wing bulkheads	Smooth plate
Developable surfaces	CL bulkhead (oil tight or non tight)	Dished plate
Compound curvature	Wing bulkhead P/S	<b>Shell and Deck Longitudinals</b>
No bulbous bow		None
Cylindrical bulbous bow		Flat bars
Bulbous bow with compound curvature	<b>Machinery</b>	Angles
Cylindrical bow	Single screw slow speed diesel	Tees
Single screw stern	Single or twin screw medium speed diesels	Bulb flats
Single screw stern with bulb		Rolled vs fabricated sections
Twin screw stern		Unidirectional system
<b>Deckhouse</b>	<b>Pumping System</b>	
Block configuration	Variable	
Straight sides and ends		
Flat decks	<b>Rudder</b>	
	Horn type	
	Spade type	

<b>Deck</b>	Main Deck/Sheer Strake Connection	Accuracy
No sheer		Normal Standard
No camber	Square (sheer stroke extends above deck)	High standard
Parabolic camber		
Straight line camber with C.L. knuckle	Radiused	Shipyard Facilities
Straight line camber with knuckle P/S	Blocks	cranes
Single vs double skin	Number of blocks	Transportation
	Size and weight	Automation
	Structural complexity	Material throughput
Main Bulkheads	Number of pieces	Process lanes
Stiffened Plate	Shoring, pins or jigs	structural Details
Corrugated	Number of turns	Stsndard
Double Plste		Specialized/Fitted
	Material	
Girders	Mild Steel (MS)	coatings
Stiffened plate	High strength steel (HSS)	Pre-construction primer
Swedged plate	Combination (HSS/MS)	standard quality
		High quality
Plate	welding	Design
Fist	Manual	Standardization
Swedged	Automatic	
Corrugated	Robotic	
Dished		Maintaiability, Strength and Fatigue
Inner Hull Connection to Inner Bottom	Plate Forming	Accessibility
	Rolling	Smooth surfaces
Bracketed	Pressing	structural intersection.
Sloped hopper	Line Heating	
Sloped hopper with formed comers		
Radiused caner (unidirectional designs)		

**Table VII: GENERIC ALTERNATIVE STRUCTURAL SYSTEM CONCEPTS**

Component or Element	Characteristics	Component or Element	Characteristics
1. Hull Form	Baseline	14. Main Deck/Sheer Strake (Gunwale) Connection	Baseline
2. Deckhouse	Baseline		
3. Tank Arrangement	Per Alternative	15. Blocks	Baseline
4. Machinery	Bsseline	16. Material	Per Alternative
5. Pumping System	Baseline	17. Welding	Per Alternative
6. Rudder	Baseline	18. Plate Forming	Per Alternative
7. Shell	Per Alternative	19. Accuracy	Baseline
8. Shell and Deck Longitudinals	Per Alternative	20. Shipyard Facilities	Baseline
9. Deck	Baseline	21. Structural Details	Per Alternative
10. Main in Bulkheads	Per Alternative	22. Coating	Baseline
11. Girders	Baseline	23. Design (Standardization)	Per Alternative
12. Plate	Per Alternative	24. Maintainability, Strength and Fatigue	Baseline
13. Inner Hull Connection to Inner Bottom	Per Alternative		

**Table VIII. BASELINE DOUBLE HULL TANKER PRINCIPAL CHARACTERISTICS**

	<b><u>40KDWT</u></b>	<b><u>95KDWT</u></b>
Length B.P. (LBO)	183.00M	234.00M
Breadth B	31.00M	41.50M
Depth D	17.70M	19.75M
Design draft	11.28M	13.75M
Block Coefficient C <sub>b</sub>	0.80	0.83
SHP	8,500	13,000
Displacement	52,790MT	114,280MT
Lightship	12,790MT	19,280MT
Wing Tank Width	2.20M	2.70M
Double Bottom Width	2.20M	2.20M
Cargo Tanks	7 @ 17.90M	7 @ 25.06M

**Table IX: UNIDIRECTIONAL DOUBLE HULL ALTERNATIVES**

<b><u>95 KDWT</u></b>	<b><u>U1</u></b>	<b><u>U2</u></b>	(Dished Plate)
Breadth B	40.75M	41.8 M	40.4M
Depth D	21.0 M	22.4 M	21.2M
Wing Tank Width	2.0 M	2.2 M	2.2M
Double Bottom Depth	2.6 M	2.2 M	2.2M
Bottom Girder Spacing	1.75M	1.15M	2.4M
Side Girder Spacing	1.45M	1.15M	2.4M
Deck Void Depth	1.0 M	2.2 M	2.2M
<b><u>40 KDWT</u></b>	<b><u>U4</u></b>	<b><u>U5</u></b>	(Dished Plate)
Breadth B	30.5 M	30.85M	30.8M
Depth D	17.57M	19.35M	18.8M
Wing Tank Width	2.0 M	2.2 M	2.2M
Double Bottom Depth	2.6 M	2.2 M	2.2M
Bottom Girder Spacing	1.75M	1.15M	2.4M
Side Girder Spacing	1.45M	1.15M	2.4M
Deck Void Depth	1.0 M	2.2 M(open to cargo)	2.2M

**Table X COMPARISON OF PRODUCTIVITY** (Baseline of 1.0 for Japan, unless otherwise specified) (1992), PI.

<b><u>Item</u></b>	<b><u>U.S.*</u></b>	<b><u>Japan</u></b>
ships	Construction of five 80,000 dwt class tankers.	
Area of plant	2.5	1.0
Travel distance of materials	5.0	1.0
Number of built-up blocks	209	250
Period required for delivery of the first ship (after contract)	140 Weeks (2.33)	60 weeks (1.0)
Labor hours for first ship	1,374,000 (2.31)	594,000 (1.0)

- \* U.S. superior points: outfit, piping construction. source: U.S. Maritime Administration  
U.S. inferior points: designing techniques, casting techniques, production control.

Table XII provides data for five single hull vessels built and delivered at IHI Yokohama Shipyard in the year 1972, [6]:

Table XI: LABOR ALLOCATION (High-class cargo ship) (1985), [8].

	<u>Labor % Automated Yard</u>	<u>Labor % Conventional Yard</u>
Steel fabrication	3	4
Panel and shell	4	6
outfitting:		
Electrical	4	<b>4</b>
Pipe	2	<b>3</b>
Machinery	4	<b>5</b>
Other	5	<b>5</b>
Subassembly	22	<b>11</b>
Block assembly	31	-
Ship erection	14	<b>30</b>
Launch	1	<b>1</b>
Post-launch outfit	10	<b>31</b>
	100%	<b>100%</b>
Total labor hours	68%	100%
Time required	54%	100%

Table XII: DATA ON  
SINGLE HULL SHIPS  
BUILT AT IHI in 1972, [6]

<u>Type</u>	<u>Size</u>
OBO	224,070 dwt
Tanker	230,906 dwt
Tanker	227,778 dwt
Tanker	219,803 dwt
Tanker	232,315 dwt

savings, this effects a higher facility utilization (more throughput), resulting in higher return on investment capital. For this comparison, an automated yard is one in which investments have been made into increasing automation, i.e. automatic beam forming, cranes with pneumatic or magnetic lift, self traveling staging, welding, robots, etc.

The beneficial impact of statistical accuracy control on labor hours has been discussed in various references, [9] through [14]. These studies indicate that potential improvements of 15% or more are attainable by the employment of this technique, which result in the virtual elimination of unnecessary fitting and rework. Such improvements have already been achieved in some Far Eastern yards.

Table XII provides data for five single hull vessels built and delivered at IHI Yokohama Shipyard in the year 1972, [6].

The new construction of Table XII was achieved with one building dock, supported by two 120-ton cranes and one 30-ton crane, [15]. The area of the yard used for such construction was just over 50 acres. From details of the labor force provided in [6], it may be deduced that an average of 988,000 labor hours per vessel, excluding design hours, was required for

construction.

Recent labor hour distribution data for construction of 40 and 95 KDWT double hull tankers in Japan was obtained from [6] and data for construction of an 84KDWT double hull tanker in Denmark was obtained from [5]. This data is summarized in Table XIII below. Tables XIV and XV give the steel and outfitting breakdowns of Table XIII.

To produce the Table XIV breakdown of steel labor hours, the original categories received from the Danish shipyard (steel processing, sub-assembly, flat and curved panels, blocks, erection, transport and riggers) were re-combined to better compare with those of the Japanese shipyard so that a meaningful comparison of labor hours could be made. Note that the Danish coating of cargo and water ballast tanks were subcontracted. It can be seen that if this item is added into the Danish total, then their outfitting percentage would increase and their steel percentage would decrease, possibly coming into closer agreement with the Japanese values.

If it is assumed from Table XIII that an average of 59% steel and 41% outfit breakdown in labor hours was consistent with Japanese production in 1972, then the 988,000 labor hours derived from Table XII for single

hull tanker construction in Japan would divide into 582,000 labor hours for steel and 405,100 labor hours for machinery/outfitting. Some support for assuming identical distribution of labor hours in 1972 and 1994 can be gleaned from a consideration of the advances made in shipyard steel fabrication through automation, and at the same time the modular nature of some of the outfit delivered to a shipyard together with pre-outfitting. The above data can then be used to estimate the labor hours required in Japan in 1972 to construct 40K, 95K and 84K double hull tankers, and then to project the estimates to 1994.

For this propose, it has been assumed that the total steel labor hours vary in some manner with the total weld length required for construction. To determine the relationship between weld length and vessel dimensions, a flat plate structural unit with longitudinals and transverse webs was first considered. As shown in [2], the total length of welds for the complete unit varies with the area of the flat plate panel.

To extend this reasoning to a ship, it may therefore be assumed that the total length of welds (and therefore the steel labor hours) in similar ships, with similar construction and block coefficients, varies approximately with an area numeral such as  $L(B+D)$ . For a better account of welding on main transverse bulkheads, a factor  $xBD$  may be added, where  $x$  is the number of bulkheads. For comparing ships with different internal arrangements however, such as single hull and double hull tankers, the numeral must be modified to take account of the inner bottom, the side tanks and any additional longitudinal bulkheads. Thus, for a single hull tanker with two longitudinal bulkheads and say ten transverse bulkheads, the numeral becomes  $N_s = (2LB + 4LD + 10BD)$ . For a double hull tanker with a center-line longitudinal bulkhead and ten transverse bulkheads, the numeral becomes  $N_D = (3LB + 5LD + 10BD)$ .

The average Japanese tanker deadweight in Table XII was taken to be 228,000 tons (single hull) and estimated dimensions of the vessel were derived. The dimension of the 84KDWT Danish double hull tanker were obtained from [5], while the dimensions of the 40K and 95KDWT double hull tankers are those given herein for the baseline vessels.

Table XVI was then prepared, providing a comparison of labor hours for the construction of tankers in Japan in 1972. The labor hours for construction of the 228KDWT single hull tanker were derived previously by assuming steel labor hours and machinery/outfitting labor hours to be 59% and 41% of the total hours respectively. The steel labor hours for the 40K, 95K and 84KDWT double hull tankers were

then obtained from those of the 228KDWT tankers by application of the factors  $N_D/N_s$ . The resulting hours were then taken to be 59% of the total, with the remaining 41% applying to machinery/outfitting. Total labor hours were increased by 50,000 for design, as surmised from [16], although this figure appears to be quite optimistic.

To estimate the increase in productivity in Japan by 1994 half of the improvement introducibility indicated in Table XI for automation (i.e. 16%) and half of the improvement previously discussed for statistical accuracy control (i.e. 7.5%) were taken as having occurred by 1972, as significant strides had been made in the construction of large tankers by then. The labor hours for construction in Japan in 1994 can then be derived from those in Table XVI (excluding design hours) by applying similar percentage improvements from 1972 to 1994, i.e. by multiplying by  $0.84 \times 0.925 = 0.777$ .

Using the 1994 values of steel and machinery/outfitting labor hours derived in this manner, a comparison can be made using both the Japanese and Danish labor hour breakdown percentage of Tables XIII through XV to construct Tables through XIX. These Tables represent an estimate of the labor hour distribution for the 40K and 95KDWT base alternatives and an 84KDWT tanker, using 1994 estimates of total labor hours. It should be noted that the total hours for the 84KDWT data are based on the Japanese data, but its labor hour distribution is based on the Danish data. The latter distribution has been included for purposes of comparison. It may be noted that the total labor hours for the 84KDWT vessel compare favorably with those for an 80KDWT tanker given in Table X, although it is not known whether the latter vessel was a single or double hull tanker.

According to information recently received, [17], the following labor hours for construction were achieved by Japanese and Korean shipyards in 1992:

	<u>Japan</u>	<u>Korea</u>
280KDWT single hull tanker	380450,000	700-800,000
280KDWT double hull tanker	\$50-650,000	850-950,000
150KDWT single hull tanker	About 300,000	About 640,000

This information indicates that the projected Far East labor hours for 40K and 95KDWT double hull tankers given in Table XVIII are supported by the Korean data.

Reference [18] states that some medium and smaller Japanese shipyards are building double hull Aframax tankers (approx. 95KDWT) for 200,000 hours. These hours and the Japanese labor hours above

**Table XIII: STEEL AND OUTFITTING RELATIVE LABOR HOURS FOR DOUBLE HULL TANKERS**

	<u>Japanese*</u>	<u>Danish**</u>
steel	55-63%	70%
outfitting	45-37% *IHI	30% **B&W

**Table XIV: STEEL LABOR BREAKDOWN FOR DOUBLE HULL TANKERS**

	<u>Japanese 40KDWT</u>	<u>Japanese 95KDWT</u>	<u>Danish 84KDWT</u>
Parts Cutting & Bending	15%	14%	13.75%
Sub-assembly	13%	13%	12.75%
Assembly	45%	48%	45.25%
Erection	27%	25%	28.25%
Steel Total	100%	100%	100%

**TABLE XV: MACHINERY/OUTFITTING LABOR BREAKDOWN FOR DOUBLE HULL TANKERS**

	<u>Jspanese 40KDWT</u>	<u>Jspanese 95KDWT</u>	<u>Danish 84KDWT</u>
Machine Shop			2%
Pipe fab. and machinery pkgs.	11%*	10%*	10%
Pipe installation			21%
Misc. steel outfitting			17%
Hull & Accommodation	25%*	23%*	
Mechanical Installation			8%*
Joiners & carpenters			8%*
Machinery Outfitting	18%	16%	
Electrical Outfitting	9%	9%	16%
Tests & trials incl. Dry Dockg.	6%	8%	
Painting	31%	34%	18% Danish coating of cargo -----& WE tanks subcontracted
outfitting totals	100%	100%	100%

\*Affected by hull structural concept

**Table XVI: ESTIMATED LABOR HOURS JAPAN 1972  
(All vessels double hull except 228KDWT)**

<u>DWT (M.T.)</u>	<u>LxBxD (meters)</u>	<u>N<sub>s</sub> or N<sub>D</sub></u>	<u>N<sub>D</sub>/N<sub>s</sub></u>	<u>Steel Hours (59%)</u>	<u>Machy/Outfit Hours (41%)</u>	<u>Total * Labor Hours</u>
228K	313x51x26.18	N <sub>s</sub> =78055	-	582,920	405,080	1,038,000
40K	183x31x17.7	N <sub>D</sub> =38702	0.50	291,460	202,540	544,000
95K	234x41.5x19.75	N <sub>D</sub> =60437	0.77	448,848	311,911	810,759
84K	229x32.24x21.6	N <sub>D</sub> =53845	0.69	402,215	279,505	731,720

\* Includes 50,000 hours for design [1]

Table XVII: ESTIMATED STEEL LABOR HOURS (Japan 1994)

	<u>40KDWT</u>	<u>95KDWT</u>	<u>84KDWT</u>
Parts Cutting & Bending	33,970	48,826	52,972
Sub Assembly	29,440	45,338	39,846
Assembly	101,909	167,402	141,416
Erection	61,145	87,189	88,287
Steel Total	226,464	348,755	312,521

Table XIII: ESTIMATED MACHINERY AND OUTFITTING LABOR HOURS (JAPAN 1994)

	<u>40KDWT</u>	<u>95KDWT</u>	<u>84KDWT</u>
Machine Shop			4,343
Pipe Fab. & Mach. Packages	17,311*	24,235*	21,717*
Pipe Installation			45,607*
Misc. steel Outfitting			36,920*
Hull & Accommodations	39,344*	55,742*	
Mech. Installation			17,374*
Joiners & Carpenters			17,374*
Machinery Outfitting	28,327	38,777	
Electrical outfitting	14,844	21,812	34,748
Tests & Trials inc. Dry Docking	9,442	19,388	
Painting	48,786	82,401	39,092
			(Danish coating of Cargo and WB tanks subcontracted)
Machinery & Outfitting Total	157,374	242,355	217,175

\*Affected by uniqueness of hull structural concept and difference from base vessel.

Table XIX: TOTAL STEEL, MACHINERY &amp; OUTFITTING (Japan 1994)

Total Steel & Machinery Outfitting	383,838	591,110	529,696
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are so low compared with historical and other data bases that for the purposes of this study the Korean hours have been taken to be typical of Far East construction.

Figure 12 provides the Danish B&W yard's "Learning Curve" for series production of 17 double hull tankers of 84KDWT, [51]. The production index of that figure shows that after production of the 17 vessels, the index dropped from 100 down to nearly 50. Stated another way, a shipyard building such a series design can construct the last vessel in one half the labor hours of a shipyard with a one-off design. This displays a clear case for series production and its effect on

producibility which, on face value, is likely to overshadow any other improvements on producibility.

However, the advantage of series production is available to all shipyards. A learning curve is not a fixed line and can be improved (i.e. displaced downwards) by superior work methods or design changes. A shipyard that can improve a learning curve by constant small downward displacements will be more competitive.

## APPLICATION OF ALTERNATIVE STRUCTURAL SYSTEMS

From the list of generic alternative structural system concepts given in Table VII, a series of alternative concepts was identified for study and evaluation for both the 40K and 95KDWT vessels.

For the identification of the various structural alternatives, a key code was established as follows. The key number for each 40KDWT alternative starts with 40 and ends in a number such as 10, assigned to identify the structural configuration of the alternative. For example, the 40KDWT base alternative has the number 4010 assigned to it. The other 40K alternatives have numbers 4020, 4030 etc. assigned to them. Similar key numbers, such as 9510, 9520 etc. have been assigned to the 95KDWT alternatives. A full list of the alternatives investigated, together with their key numbers, is provided in Table XX. These numbers appear on all calculation sheets. Alternatives 9590 through 95112, 95130, 95140 and 95150 were not evaluated since experience with other alternatives indicated that the relationship of their producibility to the remainder of the 95KDWT series would not differ greatly from the relationship exhibited by the 40KDWT series.

A midship section was synthesized for each structural system concept considered. The midship scantlings for all longitudinal items were obtained from the American Bureau of Shipping (AIM) program OMSEC, which incorporates all pertinent sections of ABS Rules.

It should be noted that stiffener sizes were selected from a limited range of flat bars and built-up shapes included in the program which can result in some stiffeners being oversized. This procedure was followed since it is the practice in some shipyards to restrict stiffener sizes to a limited range to simplify storage, handling and design details. However, intermediate sizes of stiffeners were also added to the program and alternatives 4030 and 9530 included in the list of structural alternatives studied, so that any oversized stiffeners could be replaced by smaller sizes. Alternatives 4030 and 9530 are otherwise similar to the base alternatives 4010 and 9510 respectively. Since they are not included in the OMSEC program, the scantlings of transverse structure and bulkheads were determined from ABS Rules for the 40KDWT and were adapted from similar ship's drawings for the 95KDWT alternatives.

For the unidirectional alternatives, an assumed spacing of longitudinal girders was used to enable the OMSEC program to calculate the required minimum ABS Rule shell plating thickness. In addition, some

approximate calculations were **performed to** obtain representative scantlings for the longitudinal girders.

For the dished plate unidirectional alternatives, plating thickness was estimated by considering the additional strength due to curvature over an equivalent flat plate structure. It should be noted that the spacing of longitudinal girders for the dished plate vessels is greater than that of the other unidirectional alternatives, as approximately identical shell thickness was maintained and the additional strength due to curvature allowed greater girder spacing. Also, the scantling of the dished plate double hull were maintained constant around the entire periphery of the midship section. This feature, which can be applied to any of the unidirectional alternatives, enables the number of unique structural blocks to be considerably reduced, but incurs some weight penalty.

To simplify the producibility investigation, yet keep it meaningful, only one midship cargo tank length of each structural alternative concept, including one transverse bulkhead, was selected for initial comparison and evaluation.

Since the producibility study required seams and butts of plating to be located, it was then necessary to break down the midship tank structure into suitable blocks for erection, as shown in Figure 13 for the 40KDWT vessels. The breakdown for the 95KDWT vessels is similar.

The lengths of the blocks were based on the length of cargo tanks (17.9m. for 40K and 25.06m. for 95KDWT alternatives) and the 3.58m. spacing of transverse floors and webs. Thus, the block lengths are 7.16m. forward and 10.74m. aft for 40K and 10.74m. forward and 14.32m. aft for 95KDWT alternatives. These arrangements provide some repetitive blocks within the parallel mid-body of the vessels. The transverse bulkheads inside the double hull formed separate blocks.

## ESTIMATES OF PHYSICAL PRODUCTION CHARACTERISTICS

In considering the producibility of the various alternative structural system concepts, it is necessary to consider many characteristic aspects of the structure, including the following, [20]:

- amount of welding
- type and number of frames, and stiffeners
- number of unique pieces
- total number of pieces
- weight
- surface area for coatings
- number, type and position of welded joints



Table XX: ALTERNATIVE STRUCTURAL SYSTEM CONCEPTS

NOTE All vessels 4010 through 4090 and 9510 through 9580 have high strength steel (grade AH32) in the deck and bottom except 4020 and 9520. All unidirectional vessels are mild steel except 40112, which has high strength steel in the deck and bottom. All vessels have conventionally stiffened transverse bulkheads (vertical stiffeners) and center line bulkheads (longitudinal stiffeners), except where noted otherwise.

**Key Nº**

- 4010- 40KDWT base vessel with square (bracketed) lower outboard corner of cargo tank.
- 9510- 95KDWT base vessel with sloped tank side (hopper] at lower outboard corner.
- 4020- Same as 10, except all mild steel.
- 9520- Same as 10, except all mild steel.
- 4030- Same as 10, three times the stiffener sizes in order to minimize weight.
- 9530- Same as 10, with additional stiffener sizes, as in 4030.
- 4040- Same as 10, with vertically corrugated transverse bulkhead.
- 9540- Same as 10, with vertically corrugated transverse bulkhead.
- 4050- Same as 60, but sloped hopper fitted with formed corners.
  
- 9550 - Same as 10, but sloped hopper fitted with formed corners.
- 4060- Same as 10, but with sloped hopper at lower outboard corner.
- 9560- Same as 10, but with square (bracketed) lower outboard corner of tank.
- 4070- Same as 10, but with bulb plates in lieu of other stiffeners.
- 9570- Same as 10, but with bulb plates in lieu of other stiffeners.
- 4380- Same as 10, but with stiffened elements fashioned from one frame space width of plate with stiffener formed on one side. This in lieu of plate stiffener combinations.
- 9580- Same as 10, but with stiffened elements fashioned from one frame space width of plate with stiffener formed on one side. This in lieu of plate stiffener combinations.
- 4090- Same as 10, but with all floor, girder and web stiffeners assumed automatically welded.
- 40100- U4 - Unidirectional alternative with vertically corrugated transverse and center line bulkheads.
- 40110- U5 - Unidirectional alternative with vertically corrugated transverse and center line bulkheads.
- 40111- U5 - Unidirectional alternative with double plate transverse bulkhead and vertically corrugated center line bulkhead.
- 40112- U5 - Unidirectional alternative with high strength steel deck and bottom, vertically corrugated transverse bulkhead and no center line bulkhead.
- 40120- U6 - Dished plate unidirectional alternative, with vertically corrugated transverse and center line bulkheads. Dished plating formed by rolling.
- 95120- U3 - Dished plate unidirectional alternative, with vertically corrugated transverse and center line bulkheads. Dished plating formed by rolling.
- 40121- U6 - Dished plate unidirectional alternative - same as 120, but dished plating formed by pressing and credit given for unique welding. Also, floor, girder and web stiffeners assumed automatically welded.
- 95121- U3 - Dished plate unidirectional alternative - same as 120, but dished plating formed by pressing and credit given for unique welding. Also, floor, girder and web stiffeners assumed automatically welded.
- 40130- Same as 10, but double bottom floors and girders lugged and slotted into bottom shell and inner bottom for easier alignment.
- 40140- Same as 10, but 50% labor hour reduction for series production of standard vessels.
- 40150- Same as 10, with use of design standards for contract/detail designs. Design labor hours reduced from 200,000 to 100,000 and schedule reduced to suit.

- |   |   |
|---|---|
| <ul style="list-style-type: none"> <li>• self-alignment and support</li> <li>• need for jigs and fixtures</li> <li>• work position</li> </ul> | <ul style="list-style-type: none"> <li>• number of physical turns/moves before completion</li> <li>• aids in dimensional control</li> <li>• space access and staging</li> </ul> |
|---|---|

- standardization
- number of compartments to be entered to complete work

The quantification of these characteristics for producibility considerations should generally be in terms of physical quantities, i.e. weight, number of pieces, number and length of welded joints, etc., or the labor hours and schedule time required for their construction or application. The remainder of this sub-section describes how the physical quantifications were made.

The structure of one complete midship tank section for each alternative, port to starboard, including one transverse bulkhead, was studied for the purposes of considering producibility. Following the breakdown into structural blocks, the quantification of the characteristics noted above then required each one tank length alternative to be broken down into all its component plates, longitudinals, stiffeners, brackets and chocks. A spreadsheet computer program was utilized for this purpose to form the basis for quantifying the various physical steel construction properties of the alternatives, including the number of unique pieces, total number of pieces, dimensions and thickness of plates, type, length, thickness and cross section area of longitudinal and stiffeners, surface areas of plates, longitudinals and stiffeners, weights, weld type (automatic, manual, fillet, butt), weld position and weld length. These properties of the various alternatives were derived for each structural block and then totalled for all blocks. Metric units were used throughout.

Manual and automatic welding processes were considered for both fillet and butt welds. Longitudinal erection seams were assumed to be automatically welded, while transverse erection butts were assumed to be manually welded. Elsewhere, manual or automatic welding was assigned. Plate thicknesses were subdivided for welding purposes according to whether they were less than/equal to 19 mm or greater than 19mm, since the latter require significantly more edge preparation than lesser thicknesses, such as 10 to 16 mm., [21]. Weld length for plates was split up into flat and curved plate categories. Weld positions considered were flat (i.e. downhand), horizontal (on sloping or vertical structure), vertical and overhead.

The welding of the hull structure of the unidirectional alternatives was assumed to be conventional, i.e. longitudinal plate seams butt welded clear of longitudinal girders, which are fillet welded to the shell plating etc. However, for the dished plate unidirectional alternatives, it is understood that a highly automated welding process is being developed for the welding of the longitudinal girders to the shell plating etc., [22] [23]. As shown in Figure 6, the junction of

a longitudinal girder with adjacent panels of dished plating forms a 3 way joint. Since it is believed that this joint is welded completely by the above process, it would appear that the welding must be performed with the joint set vertically. Robotic welding of the girder stiffeners has also been proposed.

For estimating steel labor hours for the dished plate unidirectional alternatives 40120 and 95120, welding of the 3 way joints was assumed to be equivalent to automatic vertical butt welding, with manual welding of the girder stiffeners. However, in anticipation that the special welding technique referred to may be transportable in some form to an existing U.S. yard without existing facilities enhancements, dished plate Unidirectional alternatives 40121 and 95121 Were considered to be welded with this technique, to represent the application of such technology. The labor hours for the vertical 3 way joints were then taken identical to those for the fastest conventional welding, i.e. automatic downhand welding. Automatic welding of the girder stiffeners was also made, so as to mimic the proposed robotic welding. It should be noted that the 3-way joints could also appear in the smooth plate unidirectional alternatives, and their application in 40121 and 95121 should be indicative of the benefit in both types of alternatives.

## LABOR HOURS AND SCHEDULES

### Approach

As indicated earlier, it was decided to estimate steel labor hours by adopting and modifying a method proposed in References [24] and [25].

U.S. shipbuilding's introduction of automation and accuracy control has been advancing but is acknowledged as being behind that abroad [8]. As a result, they were taken as one half of the 32% presented in Table XI for a Far Eastern automated yard's advantage over a traditional yard in 1985 and one half of the 15% improvement in overall production by implementation of strict dimensional controls and statistical accuracy, as discussed earlier for Far Eastern yards. Then, U.S. yards can be expected to achieve the labor hours and schedules of construction for the base alternative vessels shown in Table XXI and XXII respectively. The schedules in Table XXII, also shown in Figure 14, are from contract signing to delivery, and have been developed to incorporate about 12 months from the start of fabrication to launch, since this was required in 1983 for the last series of tankers to be constructed in the U.S. - see Figure 10. These schedules have some potential slack at the beginning and end (particularly from trials to delivery), allowing

for meeting contractual dates. It may be noted that the design labor hours were based on the anticipated performance of U.S. shipyards. It may be further noted that according to the data provided by Reference [6], there is almost no difference between the 40K and 95KDWT Far East baseline building schedules. Therefore no difference is shown in Table XXII.

#### Labor Hours For Steelwork

The following **notes** provide the assumptions, approaches and details of the method used to estimate the steel labor hours required for the construction of the various one tank length alternatives.

a) In order to estimate the steel labor hours required to construct one midship cargo tank section for the various structural alternatives, the steel labor hours required to construct the complete 40K and 95KDWT base vessels were first obtained from the total labor hours (excluding design labor) given in Table XXL. For this purpose, the average percentage breakdown of steel versus outfitting hours given in Table XIII for the construction of vessels in Japan was used, i.e. 59% for steel construction and 41% for outfitting. Then total steel labor hours to construct 40K and 95KDWT base vessels are 291,460 and 448,848 respectively.

An estimate of the steel labor hours to construct one cargo tank section for the base vessels was then obtained from a consideration of the relative lengths of the separate parts of the vessels (i.e. 7 cargo tanks + bow + stern + Superstructure), the structural contents of each part and the relative complexity (e.g. curved shell plating) of the structure. Approximately 10% of the total steel hours are required.

b) In order to study the various structural one tank length alternatives, a method of estimating the steel labor hours for each, as compared with the two base designs, was now required. It was therefore decided to utilize the method provided in References [24] and [25] to obtain the labor hours to construct the various one tank length alternatives.

c) For the application of this procedure to the structural alternatives, surface preparation, coating and testing were removed from the list of work processes utilized for estimating purposes, since they were considered to be part of machinery/outfitting for the purposes of this study. However, "rework" was included as an additional factor.

#### Labor Hours For Construction Of Complete Vessels

As previously indicated, the steel labor hours for the construction of the midships one tank length alternatives were estimated to be approximately 1/10 of

the total steel labor hours for the 40K and 95KDWT designs respectively. However, to allow for the transition of cargo tank structure into the bow and stem portions of the vessels, it was decided to **maintain the steel labor hours for the construction of No. 1 cargo tank section, the bow and the stem constant for the two sets of vessel sizes and equal to the hours determined for the 40K and 95KDWT base alternatives in these areas.** The steel labor hours for the deckhouses were similarly held constant. This resulted in a constant portion of the steel labor hours for the 40KDWT alternatives of 134,300 hours and for the 95KDWT alternative 160,150 hours.

The machinery/outfitting labor hours required to construct the complete 40K and 95KDWT base vessels were taken to be 41% of the total labor hours (excluding design labor) given in Table XX.

Table XV gives a percentage breakdown of the labor hours required for machinery/ outfitting, and indicates that the labor hours required by the Japanese for painting were 31% of the total machinery/outfitting hours for 40KDWT vessels and 34% for 95 KDWT vessels. These percentages were applied to the two base vessels, and for the remaining alternatives, the labor hours for painting were varied in proportion to the surface area of the steel components.

Design labor hours for the 40K and 95KDWT alternatives were estimated at 200,000 and 225,000 hours respectively, except for alternative 40150 providing for enhanced standardization where significant detail design data or working drawings are on file, for which they were reduced to 100,000.

The total labor hours for the various alternatives were then obtained by summing up the hours for steel construction, the constant hours for machinery/outfitting, the hours for painting and the hours for design. For the baseline vessels, the resulting total labor hours for the construction of the 40K and 95KDWT alternatives in the U.S. in 1994 were 712,800 and 958,100 respectively. The results of all calculations are shown graphically in Figures 15 and 16 respectively.

#### Construction Schedules

Figure 14 and Table XXII provide the estimated construction schedules in a U.S. shipyard for the 40K and 95KDWT baseline vessels. These schedules are a modified version of those provided by Reference [6] for similar vessels building in the Far East. This reference shows almost no difference in schedules for the **40K** or 95KDWT vessels, and this is reflected in Table XXII. The Far East schedule was modified to reflect predicted U.S. attainment in 1994 as follows:

**Table XXI: TOTAL ESTIMATED LABOR HOURS  
FOR CONSTRUCTION OF BASELINE SHIPS IN U.S. IN 1994**

	<u>40KDWT</u>	<u>95KDWT</u>
Far East Base Labor Hours for construction (from Table XIX)	383,838	591,110
{Increase for U.S. due to lesser automation and accuracy control.	110,162	169,649
Design Labor	<u>200,000</u>	<u>225,000</u>
U.S. Total Labor Hours	694,000	985,759

**Table XXII: ESTIMATED SCHEDULE FOR CONSTRUCTION OF BASELINE SHIPS IN U.S. IN 1994**

	<u>40KDWT</u>	<u>95KDWT</u>
Far East Baseline Schedule, including design (from Figure 11)	20.5 months	20.5 months
{Increase for U.S. due to lesser automation and accuracy control, applied from fabrication to sea trials.	2.6 "	2.6 "
Additional Design Period	<u>6.0 "</u>	<u>6.0 "</u>
U.S. Schedule for Construction	29.1 months	29.1 months

- The design time was increased from 8 months to approximately 14 months (6 months increase) to provide additional design time for one-off ships with less incorporation of standard interim products..

- It is assumed that the time line between the commencement of steel fabrication and sea trials increase by 2.6 months to allow for the lesser utilization of automation and accuracy control U.S. shipyards.

- The time line between commencement of steel fabrication and launching was increased from 7.4 to 12.4 months, to suit the U.S. construction data for 40KDWT tankers in Figure 10. This 5 month increase was overlapped into the design period.

- The time line between sea trials and delivery (3.5 months) was unchanged assuming the same yard would produce all alternatives with a 3.5 in month sea trial to delivery time.

Thus, the U.S. baseline schedule was increased to 29.1 months, and this was used as a basis for the estimation of schedules for the various structural alternatives.

Key milestones such as the commencement of fabrication, keel laying and launching are included in Figure 14, which also incorporates time lines for assembly, erection and painting. The time spread of these time lines and the locations of the key milestones given in the Far East schedule were modified to suit the above changes. It should be noted that in preparing the basic schedule for construction in U.S. shipyards, it has been assumed that all required material and equipment would be delivered to the shipyard as required to meet the schedule. Any delay in such deliveries would impact on the schedule and increase vessel costs.

For estimating the construction schedules for the various 40K and 95KDWT alternatives, the pertinent information derived from their evaluation for this purpose consisted of the total steel labor hours and the labor hours (or surface areas of steel components) for painting. The machinery and outfitting labor hours for the 40K and 95KDWT base vessels have been assumed constant, with the exception of those required for painting. Therefore, it has been assumed that the time lines for steel assembly and erection are proportional to the total steel labor hours, and the time line for painting is proportional to the labor hours (or surface areas) required for painting. Labor hours for painting were varied in proportion to the surface areas, so that either quantity may be used to modify the time line.

As previously stated, the base construction schedule shown in Figure 14 shows key milestones in the building process, and since it was considered desirable to include these in all schedules, the following procedure was adopted to estimate the construction schedules for the structural alternatives:

- With reference to Figure 14, no change was made to the location of the milestone for the commencement of steel fabrication.

- The time line for steel assembly preceding keel laying was modified in proportion to the total steel labor hours, resulting in relocation of keel laying and all subsequent key milestones.

- The time lines for steel assembly and erection located between keel laying and launching were modified in proportion to the total steel labor hours. The time line for painting preceding launching was modified in proportion to the total painting labor hours.

Since these three construction processes overlap in this portion of the schedule, the changes in their corresponding time lines were then averaged to provide the accumulative effect upon the time required between keel laying and launching. Keel laying and all subsequent key milestones were then again relocated to suit.

1 The time line for painting following launching was modified in proportion to the total painting labor hours, resulting in further relocation of the milestones for sea trials and ship delivery.

The resulting construction schedules for all of the 40K and 95KDWT structural alternatives are shown in Figures 17 and 18 respectively. For comparison purposes, the Far East schedule of 20.5 months has also been incorporated in these figures.

The labor hours and construction schedules shown in Figures 15 through 18 for baseline vessels" constructed in the Far East are considerably smaller than those for the various alternatives constructed in the U.S. and show the effect of increased automation, increased accuracy control and reduced design labor hours, as these were the only variables considered significant in differentiating the U.S. and Far East labor hours and schedules.

In the interest of testing this hypothesis, the automation, accuracy control, and design time were improved for alternatives 4010, 4090 and 40110, yielding alternatives 4010N, 4090N and 40110N. The improvements reflect the following:

- 1 Floor and girder stiffeners are assumed automatically welded. Field welds of side shell, decks and longitudinal bulkhead are assumed automatically welded.
- 1 Accuracy control improved by careful edge preparation and increased statistical measurements reducing rework from 10% to 2%.
- 1 Design labor hours, due to standardization was reduced to 100,000 hours.

A comparison of the alternatives before and after these assumptions are shown in Figures 19 and 20 using the method of evaluations contained herein. They demonstrate that the improvements noted reduce the difference in labor hours between the Far Eastern Baseline and the U.S. constructed vessel in the order of 12%.

## CONCLUSIONS

The physical characteristics, together with the estimated labor hours and construction schedules, provide a measure of producibility of the alternative structural concepts. The estimated labor hours for construction of the 40KDWT alternatives, shown in Figure 15, indicate that the labor hours for most of the alternatives are within 20,000 (about 3%) of the 712,813 hours estimated for the baseline alternative 4010. As an example, alternative 4070 shows the benefit (about 10,000 hours reduction) of using rolled sections (bulb plates) in lieu of built-up sections. The results show that the effect of the different structural

elements used in the various alternatives is generally small. Exceptions to this trend include unidirectional alternative 40100 (+80,000 hours) and dished plate unidirectional alternatives 40120 (+150,000 hours) and 40121 (+40,000 hours). These results are perhaps surprising, since unidirectional designs incorporate significantly less structural pieces, but the increased labor hours for these vessels appears to be largely due to increased flame cutting/welding hours etc. necessitated by increased plating thickness. Also, the scantlings of dished plate unidirectional alternatives were maintained constant around the entire periphery of the midship section, which again incurs additional labor hours due to oversized Scantlings in some areas. More notable exceptions are alternative 40140, which shows the advantage of series production of the baseline vessel, assuming labor hours are halved, and alternative 40150, which shows the advantage of using standard designs for structural details, assuming the design labor hours are halved. Finally, the comparison in Figure 19 represents alternatives where the design labor hours have been halved, welding automation increased, and accuracy control increased reduce rework to 2%.

The estimated labor hours for construction of the 95KDWT alternatives, shown in Figure 16, indicate similar trends relative to the 958,082 hours estimated for the baseline alternative 9510 as exhibited by the 40KDWT alternatives. Labor hours for unidirectional alternative 95100 were not estimated, but dished plate alternatives 95120 and 95121 show about +100,000 hours and -10,000 hours relative to the baseline vessel 9510. This shows a somewhat improved level of producibility than that shown by the corresponding 40KDWT vessels.

Further to the increased plating thickness for unidirectional alternatives referred to above, this increase is due to the wider spacing of the longitudinal girders as compared with conventional longitudinal stiffeners. Some reduction in plate thickness is achieved in dished plate unidirectional designs by the adoption of curved plating, but the steel weight of both versions of the dished plate hull exceeds that of a corresponding conventional double hull design. The advantage of dished plating compared with fiat plating may be illustrated by comparing the shell plating thickness for each case, utilizing dished plate alternative 40120 with 2.4M. girder spacing. A thickness of 25.4mm. was estimated for dished plating, but this increased to 45mm. for flat plating. The steel weight of one midship cargo tank length would then increase by 37.6%, and the estimated steel labor hours would increase by 45%.

The construction schedules for the 40KDWT alternatives, shown in Figure 17, indicate that the schedules for most of the alternatives are equal to or slightly lower than that of the 29.1 months required for the baseline alternative 4010. Exceptions include 40100, 40120, 40140 and 40150, referred to in the preceding discussion of labor hours. It may be noted that the schedule for 40140 is only slightly greater than the 20.5 months required for construction in the Far

East, but of came a similar advantage for series production should be expected to apply there as well. The schedule for 40150 shows a reduction of about 3 months from the schedule for 4010.

Similar trends are exhibited by the construction schedules for the 95KDWT alternatives, shown in Figure 18. The schedule for the baseline alternative 9510 is 29.1 months, as for the 40KDWT baseline 4010.

The labor hours and construction schedule shown in Figures 15 through 18 for baseline vessels constructed in the Far East are considerably smaller than those for the alternative constructed in the U.S. Figures 19 and 20 demonstrate how improved automation, accuracy control, and reduced design labor hours can reduce the labor hours significantly. This suggests that these areas are where the greatest gains may be possible to make U.S. shipyards more productive and more competitive on a world scale. It is likely that to maximize such improvements will require facilities enhancements to mimic Table II, which is beyond the scope of this study.

The differences between the design labor hours in Japan and the U.S. can only be explained by the existence of standard ship designs and design standards in Japan. It should also be noted that the absence of such standards incurs increased risk in time phased material procurement. These differences can also suggest a production labor force which requires fewer drawings for construction, which also suggests standardization.

## ACKNOWLEDGEMENT

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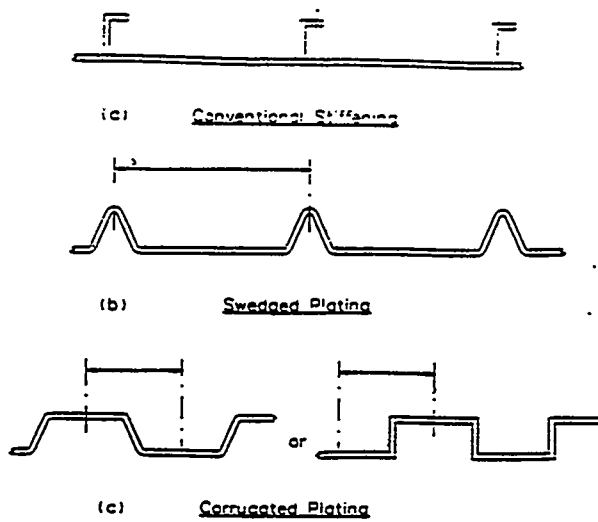


Figure 1  
ALTERNATIVE METHODS FOR STIFFENING PLATING



Figure 2  
STIFFENED ELEMENTS FORMED FROM ONE FRAME (OR STIFFENER)  
SPACE WIDTH OF PLATE WITH STIFFENER FORMED ON ONE SIDE.

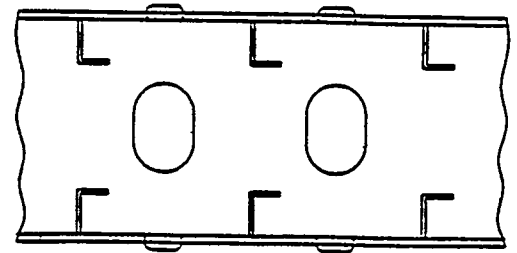


Figure 3  
LUGGED AND SLOTTED STRUCTURE

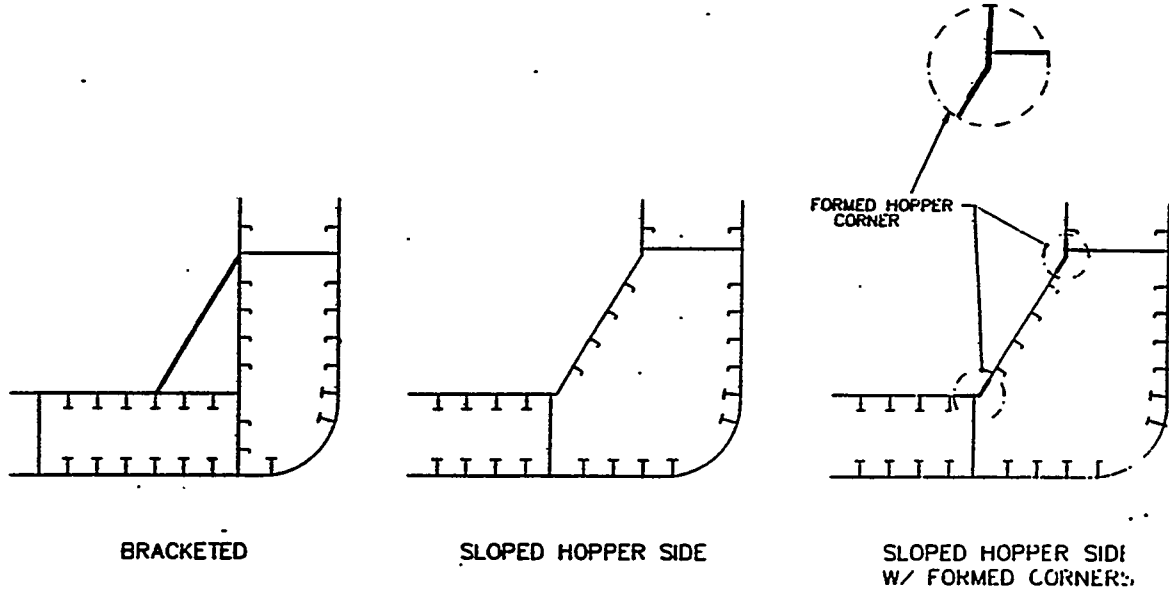


FIGURE 4 — TYPES OF LOWER HOPPER CORNERS

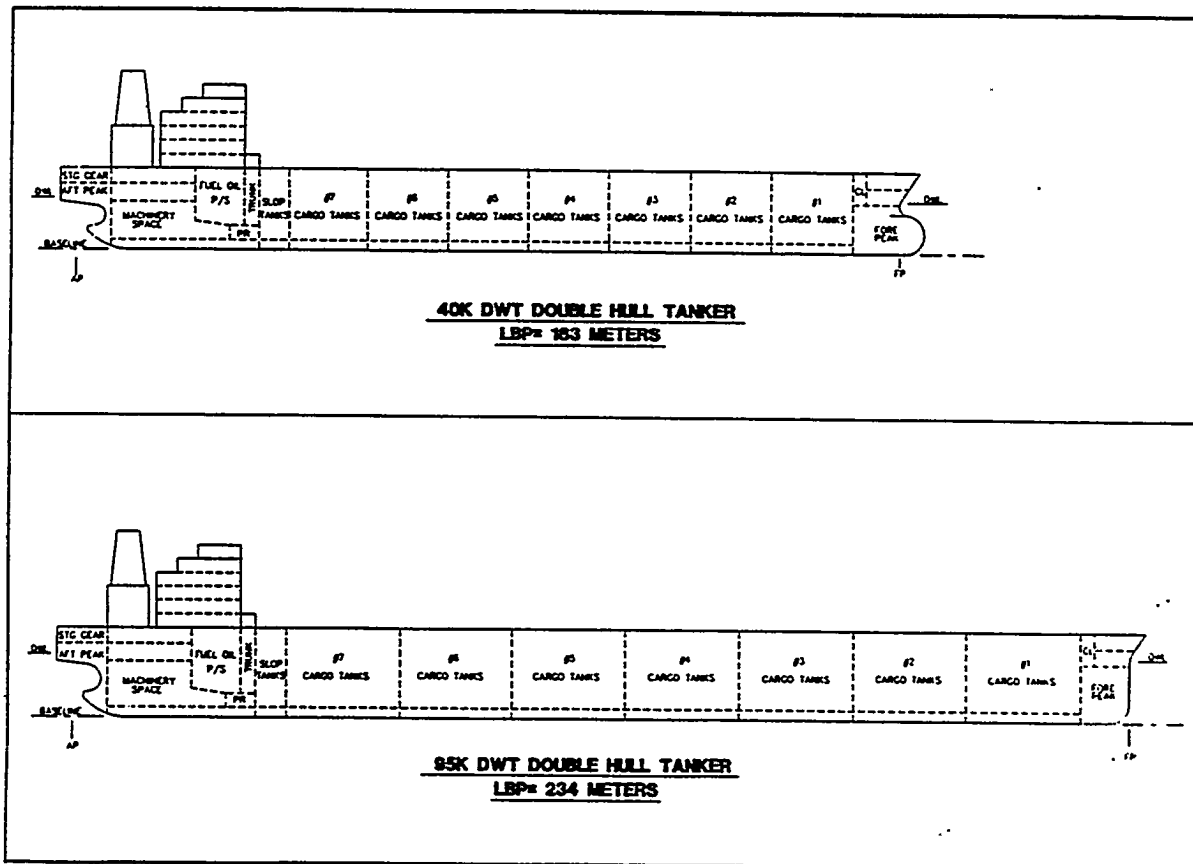
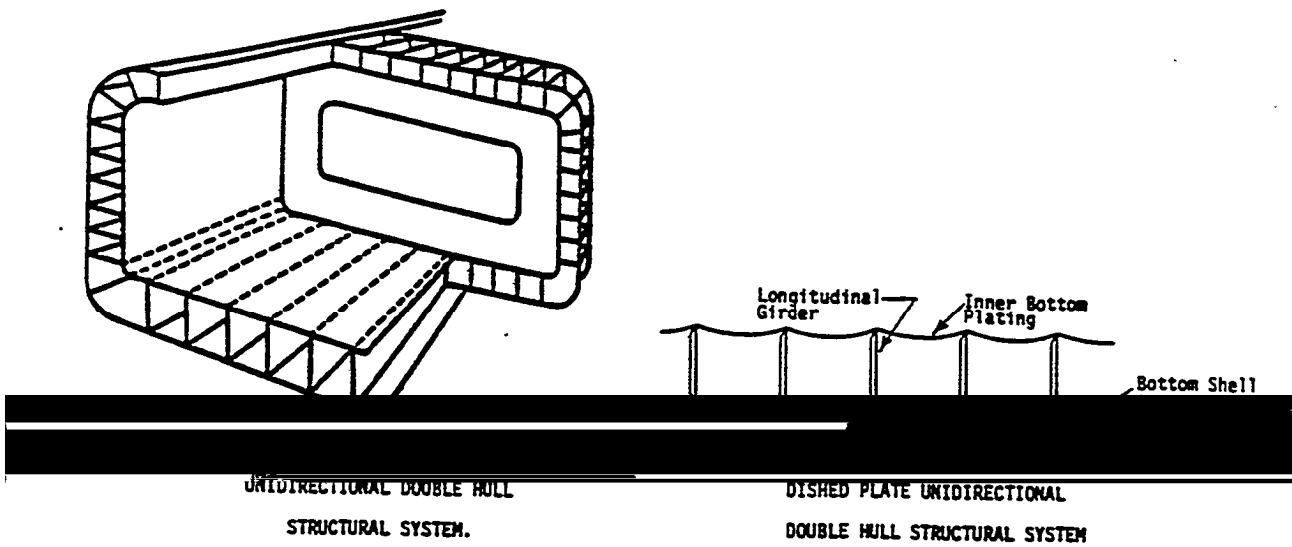


FIGURE 7- GENERAL ARRANGEMENTS



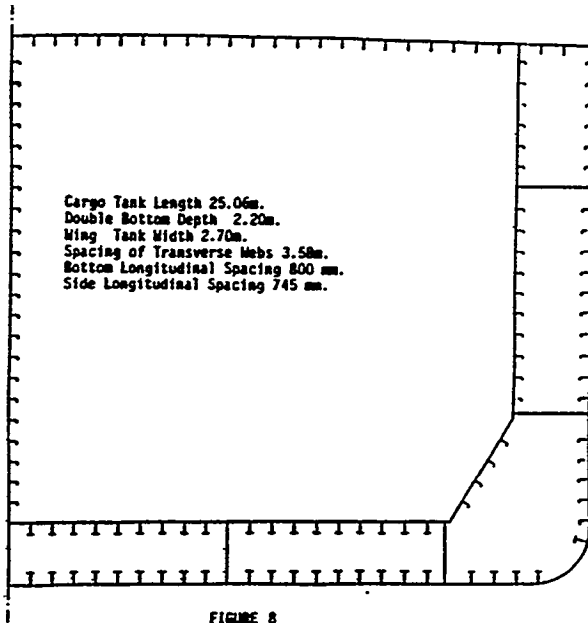


FIGURE 8  
95KMT BASELINE MIDSHIP SECTION

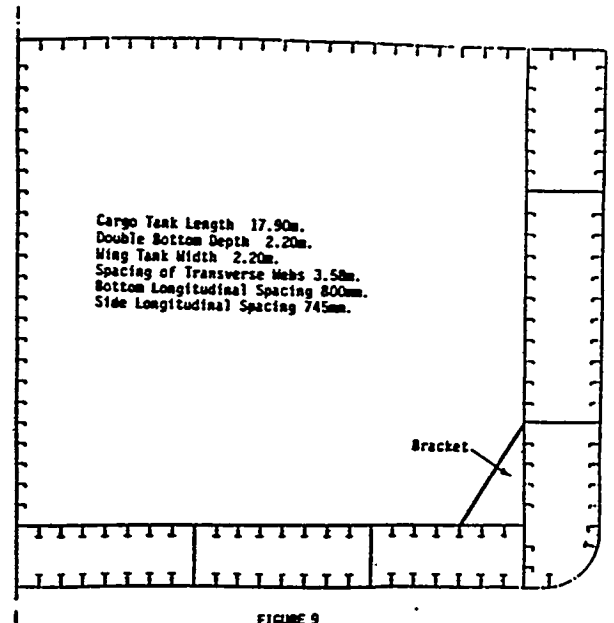
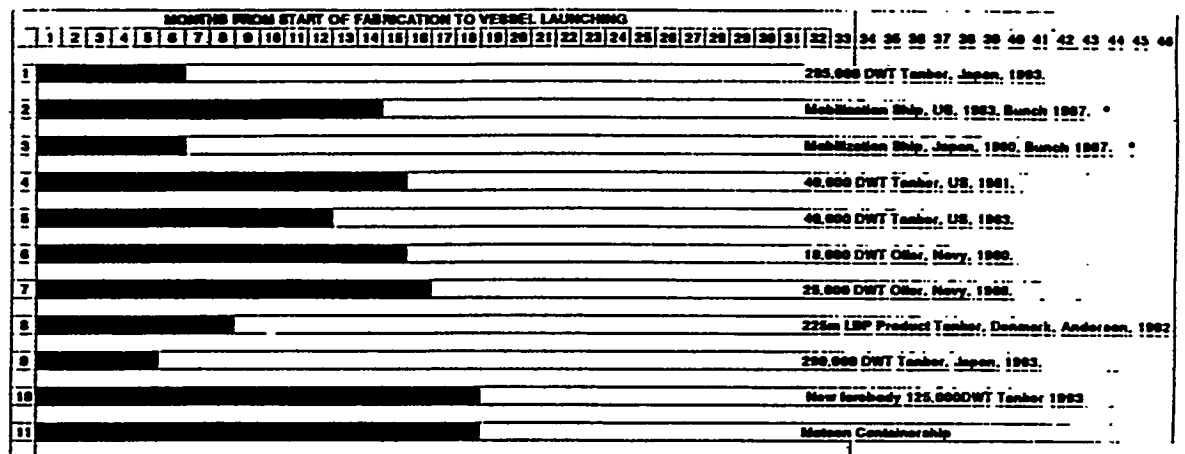


FIGURE 9  
40KMT BASELINE MIDSHIP SECTION



\* Vessels not built

FIGURE 10

### FABRICATION TO LAUNCHING TIME LINES

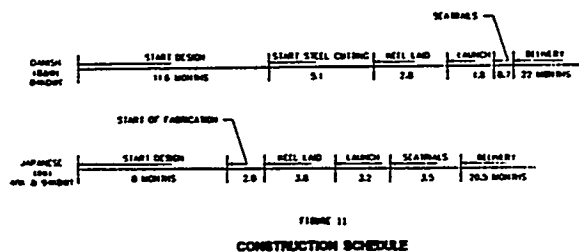


FIGURE 11  
CONSTRUCTION SCHEDULE

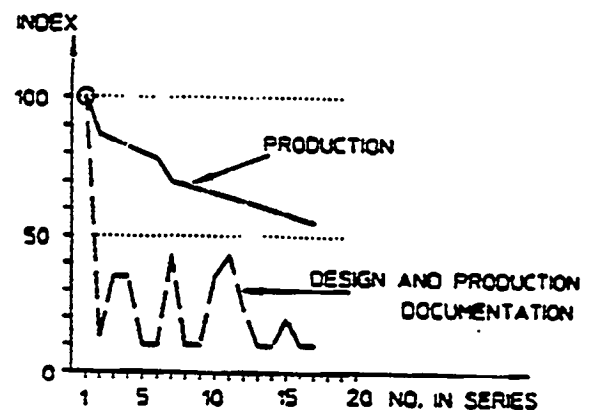


Figure 12  
Learning Curve for Series Production, [B&W]

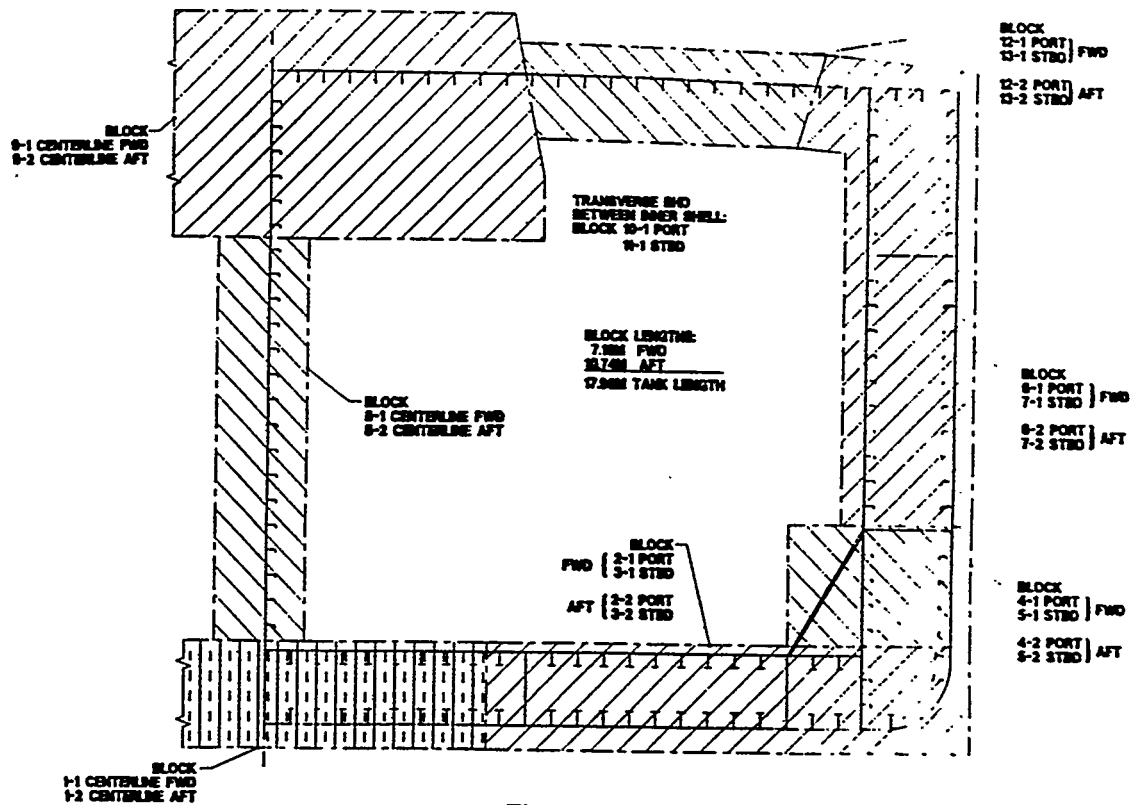


Figure 13  
BLOCK BREAKDOWN FOR 40KDWT BASELINE

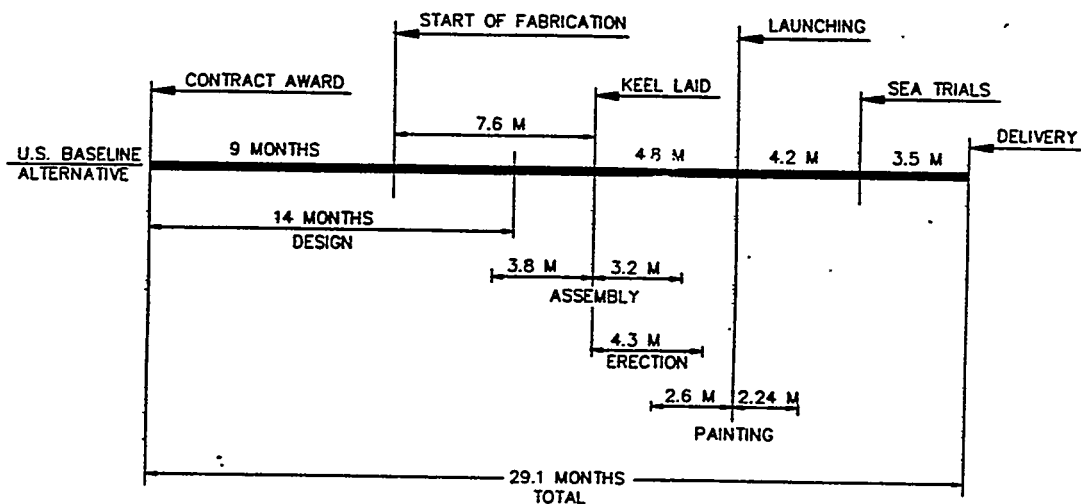


FIG. 14 - 1994 U.S. BASE TIME LINE SCHEDULE

FIGURE 15

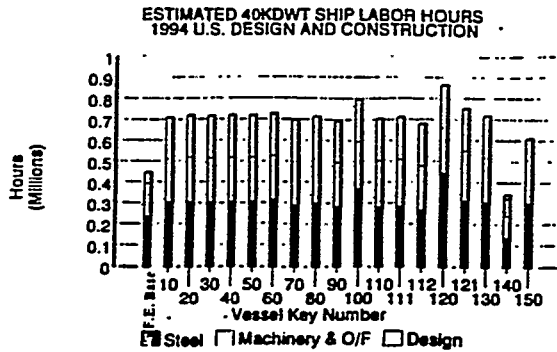


FIGURE 16

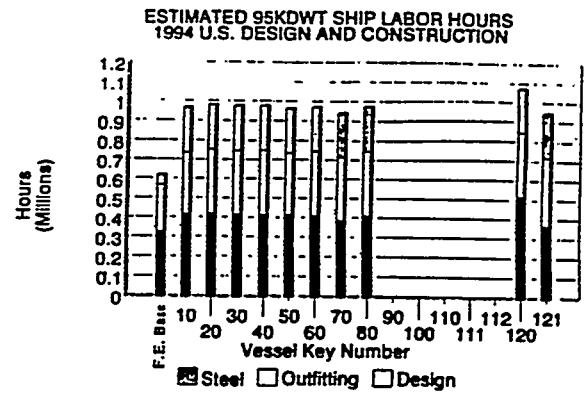


FIGURE 17

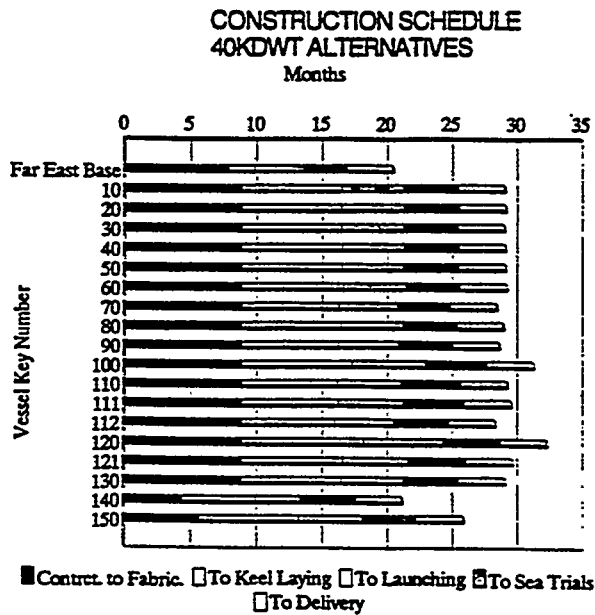


FIGURE 18

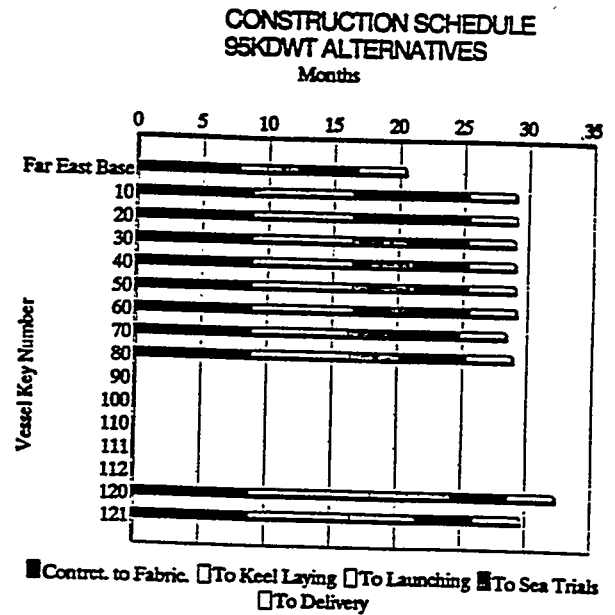


FIGURE 19

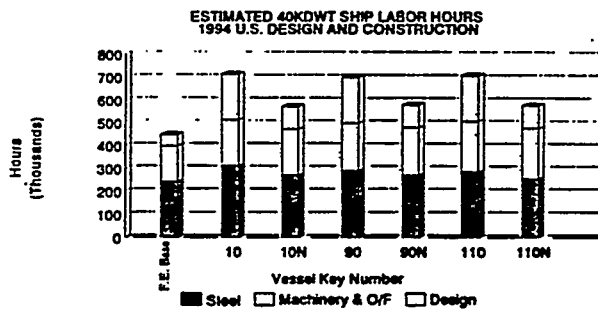
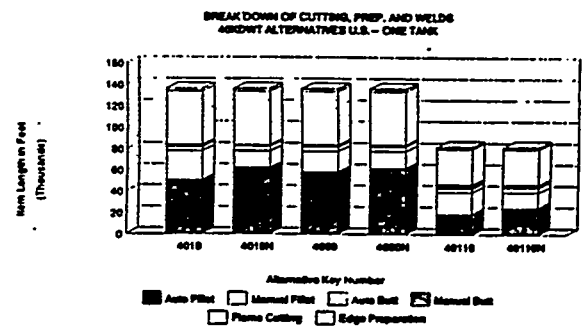


FIGURE 20





## Build Strategy Development

John Clark (V), A&P Appledore International Ltd., U. K., and Thomas Lamb (FL), Textron Marine & Land Systems, U.S.A.

### ABSTRACT

The 1985 NSRP "Design For Production Manual" (SP-4,1986) describes of a Build Strategy basis for improved shipbuilding performance through front end involvement of all departments and better COmmunication. A number of U.S. shipbuilders are known to have used the approach However, the extent of its use and the experience of the users was unknown.

To remedy this situation the SF-4 Panel conceived a project to determine;(1)how widely "the Build Strategy approach" was known and used by U.S. shipbuilders, and (2) a suitable Build Strategy framework with examples of its use for two typical ship types.

This paper summarizes the performance of the project and briefly describes the findings of the U.S. and foreign shipyard surveys and visits, the required prerequisites for use of a Build Strategy and benefits from its use. It also includes the contents list for the proposed Build Strategy framework

### INTRODUCTION

All shipbuilders plan how they will build their ships. The plan may be only in someone's head or a detailed and documented process involving many people. Often different departments prepare independent plans which are then integrated by a "Master Plan/Schedule"..

A Build Strategy is much more than the normal planning and scheduling and a description of how the Production Department will build the ship.

Many shipbuilders use the term "Mild Strategy" for what is only their Production Plan. In terms of this project, this is incorrect. The term "Build Strategy" as used throughout this paper has a special specific meaning. It is also recognized that some shipbuilders have a process very similar to the Build Strategy approach but do not call it such

What is the meaning by the term Build Strategy for this project? Before specifying this, the aims of a Build Strategy are briefly discussed

It:

- 1 applies a company's overall shipbuilding policy to a contract
- 1 provides a kprocess for ensuring that design development takes full account of production requirements,
- 1 systematically dmduces production engineering principles that reduce ship work content and cycle time,
- 1 identifies interim products and creates product-oriented approach to engineering and planning of the ship,
- 1 determines resource and skill retirements and overall facility loading,
- 1 identifies shortfalls in capacity in terms of facilities, manpower and skills
- 1 creates parameters for progmming and detail planning of engineering procurement and production activities
- 1 provides the basis on which any eventual production of the product may be orgainzed including procurement dates for "long lead" material items.
- 1 • ensures all departments contribute to the strategy,
- 1 identifies and resolves problems before Work on the contract beings, and
- 1 ensures Communication, cooperations, collaboration and consistency between the various technical and production functions.

In summary:

A BUILD STRATEGY IS AN AGREED DESIGN, ENGINEERING, MATERIAL MANAGEMENT, PRODUCTION AND TESTING PLAN, PREPARED BEFORE WORK STARTS, WITH THE AIM OF IDENTIFYING AND INTEGRATING ALL NECESSARY PROCESSES.

## **BACKGROUND**

It was A&P Appledore that conceived and developed the formal Build Strategy approach in the early 1970's. It developed from the ideas and processes generated to support the A&P Appledore associated "Ship Factories" at Sunderland and Appledore. The detailed work breakdown, formalized work sequencing and very short build cycles associated with these ship factories required the communication, coordination and cooperation that are inherent in the Build Strategy approach.

British Shipbuilders adopted the Build Strategy approach for all their shipyards (Vaughan, 1983)\* and A&P Appledore consulting group continued to develop the approach as a service to their clients.

The Build Strategy approach was introduced into the U.S. by A&P Appledore's participation in IREAPS conferences, as well as through presentations to individual shipbuilders and the SP-4 Panel (Craggs, 1983; A&PA, 1983; and A&PA, 1984).

A&P Appledore consulting to NORSHIPCO, Lockheed Shipbuilding Company and Tacoma Boat introduced the use of the Build Strategy approach to U.S. shipbuilding projects. Finally, the Build Strategy approach was described in the DESIGN FOR PRODUCTION Manual, prepared by A&P Appledore for the SP-4 Panel (SP-4, 1986).

The concept of the Build Strategy has existed for a number of years, and there has been an ongoing development of the concept in those shipyards which have adopted the Build Strategy approach. During this time, shipyards in Britain, and other countries, have had considerable experience in applying this technology, and it was appropriate to update the original Build Strategy approach in the light of this experience.

It is a known fact, but, unfortunately, a not an often practiced approach, that the performance of any endeavor will be improved by improvements in communications, cooperation and collaboration. A Build Strategy improves all three. It communicates the intended total shipbuilding project to all participants. This communication fosters improved cooperation as everyone is working to the same plan. It improves collaboration by involving most of the stakeholders (interested parties) in its development.

Why was this project necessary? It was perceived by some shipbuilders and the U.S. Navy that the formal documented Build Strategy approach had not been enthusiastically embraced by U.S. shipbuilders.

\* See REFERENCES

If the Build Strategy approach is thought to be such a good idea and/or shipbuilding improvement tool, it is surely worthwhile to try to find out if this is the case, and, also to find out why it is not being used by U.S. shipyards.

## **PREREQUISITES FOR A BUILD STRATEGY**

A Build Strategy could be produced as a stand alone document for any ship to be built by a shipyard but it would be a great deal thicker and would take a lot more effort to produce if certain other documents had not been prepared earlier.

The first of these documents would be the shipyard's Business Plan, which will probably exist in most shipyards. A Business Plan sets out the shipyard's ambitions for a period of years and describes how the shipyard aims to attain them.

Next a Shipbuilding Policy should be in place. The policy defines the product mix which the shipyard intends to build plus the optimum organization and procedures which will allow it to produce ships efficiently. The Shipbuilding Policy will also include methods for breaking the ships in the product mix into standard interim products by applying a Product Work Breakdown Structure. Areas in which the interim products will be produced and the tools and procedures to be used will also be defined.

Ideally, a Ship Definition Policy will also exist. This specifies the format and content that the engineering information will take in order to support the manner in which the ships will be built.

If any of these documents do not exist, then the information relevant to a particular contract that would have been in them will have to be produced and included in the Build Strategy.

## **RELATIONSHIP BETWEEN SHIPBUILDING POLICY AND BUILD STRATEGY**

A Shipbuilding Policy is the definition of the optimum organization and build methods required to produce the product mix contained within the company's shipbuilding ambitions, as defined in the Business Plan. The Shipbuilding Policy is aimed primarily at design rationalization and standardization, together with the related work organization, to simulate the effect of series construction. This is achieved by the application of group technology and a product work breakdown, which leads to the formation of interim product families.

A Shipbuilding Policy is developed from a company's Business Plan, which usually covers a period of five years and includes such topics as:

- the product range which the shipyard aims to build,
- shipyard capacity and targeted output,
- targets for costs, and
- pricing policy.

The product range is identified, usually as a result of a market study.

The relationship between a Business Plan, Shipbuilding Policy, and Build Strategy is shown in Figure 1.

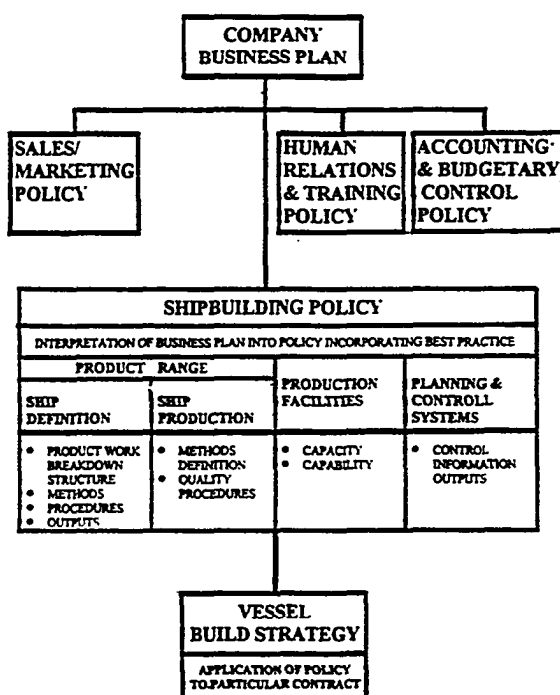


Figure 1 - Build Strategy and Shipbuilding Policy

The Business Plan sets a series of targets for the technical and production part of the organization. To meet these targets, a set of decisions is required on:

- facilities development,
- productivity targets,
- make, buy or subcontract, and
- technical and production organization.

These form the core of the Shipbuilding Policy. The next level in the hierarchy defines the set of strategies by which this policy is realized, namely the Build Strategy.

In essence, the Shipbuilding Policy comprises a set of standards, which can be applied to specific ship contracts. The standards apply at different levels:

- Strategic, related to type plans, planning units, interim product types, overall facility dimensions, and so on; applied at the Conceptual and Preliminary Design stages.
- Tactical, related to analysis of planning units, process analysis, standard products and practices, and so on; applied at the Contract and Transition Design stages.
- Detail, related to work station operations and accuracy tolerances; applied at the Detail Design stage.

Because shipbuilding is dynamic, there needs to be a constant program of product and process development. Also, the standards to be applied will change over time with product type, facilities, and technology development.

The shipbuilding policy is therefore consistent, but at the same time will undergo a structured process of change, in response to product development, new markets, facilities development, and other variations.

The policy has a hierarchy of levels which allow it to be applied in full at any time to a particular contract.

Therefore, to link the current policy with a future policy, there should be a series of projects for change which are incorporated into an overall action plan to improve productivity. Since facilities are a major element in the policy, a long term development plan should exist which looks to a future policy in that area. This will be developed against the background of future business objectives, expressed as a plan covering a number of years.

These concepts are summarized and illustrated in Tables I and II.

Work at the Strategic level provides inputs to:

- the conceptual and preliminary design stages,
- contract build strategy,
- facilities development,
- organizational changes, and
- the tactical level of shipbuilding policy.

At the strategic level, a set of documents would be prepared which address the preferred product range. For each vessel type, the documents will include:

- definition of the main planning units,
- development of type plans, showing the sequence of erection, and
- analysis of main interim product types.

TABLE 1  
ELEMENTS OF SHIPBUILDING  
POLICY

<b>POLICY OVERVIEW</b>
Policy Based on Business Plan Objectives
Sets (objectives for Lower Levels
<b>CURRENT PRACTICE</b>
Existing Standards
"Last Best" Practice
Procedures to be Applied to Next Contract
<b>PRODUCTIVITY ACTION PLAN</b>
Covers Next Twelve Months
Plans Improvements in Specific Areas
Is a Set of Projects
<b>FUTURE PRACTICE</b>
Developed from Current Practice
Incorporates Outcome of Action Plan
Procedures to be Applied to Future Contracts
<b>LONG TERM DEVELOPMENT PLAN</b>
Covers Facilities Development
Covers a Five Year Period

TABLE 2  
TYPICAL LIST OF CONTENTS IN A  
DETAILED SHIPBUILDING POLICY  
DOCUMENT

<b>1.0 OVERVIEW</b>
1.1 Objectives
1.2 Purpose and scope
1.3 Structure
<b>2.0 PRODUCT RANGE</b>
2.1 Product Definition
2.2 Outline Build Methods
<b>3.0 OVERALL PHILOSOPHY</b>
3.1 Outline
3.2 Planned Changes and Developments
3.3 Related Documents

3.4 work Breakdown Structure
3.5 coding
3.6 Technical Information
3.7 Workstations
3.8 standards
3.9 Accuracy Control
<b>4.0 PHYSICAL RESOURCES</b>
4.1 Outline
4.2 Planned Changes and Developments
4.3 Related Documents
4.4 Major Equipment
4.5 Steel Preparation and Subassembly
4.6 Outfit Manufacture
4.7 steel Assembly
4.8 outfit Assembly
4.9 Pre-Outfit Workstations
4.10 Berth/Dock Area
4.11 Engineering Department Resources
<b>5.0 SHIP PRODUCTION METHODS</b>
5.1 Outline
5.2 Planned Changes and Developments
5.3 Related Documents
5.4 Standard Interim Products, Build Methods,
5.5 Critical Dimensions and Tolerances
5.6 Steel Preparation
5.7 Steel Assembly
5.8 Hull Construction
5.9 Outfit Manufacture
5.10 Outfit Assembly
5.11 Outfit Installation
5.12 Painting
5.13 services
5.14 Productivity Targets
5.15 Subcontract Work
<b>6.0 SHIP DEFINITION METHODS</b>
6.1 Outline
6.2 Planned Changes and Developments
6.3 Related Documents
6.4 Ship Definition Strategy
6.5 Pre-Tender Design
6.6 Post-Tender Design

## 7.0 PLANNING FRAMEWORK

### 7.1 Outline

### 7.2 Planned Changes and Developments

### 7.3 Related Documents

### 7.4 Strategic Planning

### 7.5 Tactical Planning

### 7.6 Detail Planning

### 7.7 Performance Monitoring and Control

## 8.0 HUMAN RESOURCES

### 8.1 Outline

### 8.2 Planned Changes and Developments

### 8.3 Related Documents

### 8.4 Organization

### 8.5 Training

### 8.6 Safety

## 9.0 ACTION PLAN

### 9.1 Outline

### 9.2 Projects and Time scales

The strategic level will also address the question of facility capability and Capacity.

Documentation on the above will provide input to the conceptual design stage course, in those cases where agent is undertaking the design work and the builder has not been identified.

Documentation providing input to the preliminary design stage will include:

- 1 preferred raw material dimensions,
- 1 maximum steel assembly dimensions,
- 1 maximum steel assembly weights,
- 1 material forming Capability, in terms of preferred hull configurations.
- 1 "standard" preferred outfit assembly sizes, configuration and weights, based on facility
- 1 capacity/capability, and
- 1 "standard" preferred service routes.

At the tactical level standard products and production practices related to the contract and transition design stages, and to the tactical planning level will be developed. All the planning units will be analyzed broken into a hierarchy of products.

The policy documents will define preferences with respect to:

- standard interim products
- 1 standard product processes and methods,
- standard production stages,
- 1 installation practices,
- 1 standard material sizes, and
- 1 standard piece parts.

The capacity and capability of the major shipyard facilities will also be documented

For the planning units, sub-networks will be developed which define standard times for all operations from installation back to preparation of production information. These provide input to the planning function.

At the Detail level, the policy provides standards for production operations and for detail design.

The documentation will include:

- **workstation descriptions,**
- **workstation capacity,**
- **workstation capability,**
- **design standards,**
- **accuracy control tolerances,**
- **welding standards, and**
- **testing requirements.**

Reference to the standards should be made in contracts, and relevant information made available to the design, planning and production functions.

As with all levels of the shipbuilding policy, the standards are updated overtime, in line with product development and technological change.

A ship definition is a detailed description of the **procedures to be adopted, and the information and** format of that information to be produced by each department developing technical information within a shipyard. The description must ensure that the information produced by each department is in a form suitable for the users of that information.

These users include:

- shipowners or their agents
- shipyard management,
- classification societies
- government bodies,
- other technical departments
  - design and drawing offices,
  - CAD/CAM center,
  - lofting
  - planning



production engineering  
production control,  
material control,  
**estimating,**  
**procurement, and**

1 production departments

Preferably the ship under consideration would also be of a type which has been identified in the Shipbuilding Policy as one which the shipyard is most suited to build.

The next best scenario would be that the ship being designed was of a type for which a build strategy exists within the shipyard.

#### BENEFITS OF A BUILD STRATEGY TO U.S. SHIPBUILDERS

If mass production industries, such as automobile manufacturing are examined, there is no evidence of the use of build strategies.

Someshipyards, which have a very limited product variety, in terms of interim and final products, generally speaking, also have no need for build strategies due to their familiarity with the products. If such shipyards, which are amongst the most productive in the world do not use build strategies, then why should the U.S. industry adopt the build strategy approach?

The answer lies in the differences in the commercial environments prevalent and the gearing of operating systems and technologies to the product mix and marketing strategies. In a general sense, the most productive have identified market niches, developed suitable standard ship designs, standard interim products and standard build methods. By various means, these yards have been able to secure sufficient orders to sustain a skill base which has become familiar with those standards. As the degree of similarity in both interim and final products is high, there has been no need to re-examine each vessel to produce detailed build strategies, but many of them do as they find the benefits greatly outweigh the effort.

It is most likely that the U.S. shipbuilding industry's **re-entry into major commercial international markets** will begin with one-offs or at best very limited series contracts. Furthermore, as many U.S. shipyards believe that it will be most effective to concentrate on complex vessels the build strategy approach will be a key factor in enabling the yards to obtain maximum benefit from the many advanced technologies, most of which have been made available through the work of the NSRP Ship Production Panels. Also, the Build

Strategy approach will ensure that the way they are to be reapplied is well planned and communicated to all involved.

Most shipyards will have elements of a Build Strategy Document in place. However, without a formalized Build Strategy Document the lines of communication may be too informal and variable for the most effective strategy to be developed.

A well organized shipyard will have designed its facilities around a specific product range and standard production methods which are supported by a variety of technical and administrative

**developed according to the requirements of production,** and detailed in a Shipbuilding Policy. In this case, when new orders are received only work which is significantly different from any previously undertaken needs to be reinvestigated in depth in order to identify possible difficulties.

Where it has not been possible to minimize product variety, such investigations will become crucial to the effective operation of the shipyard. The outcome of these investigations is the Build Strategy Document.

A Build Strategy is a unique planning tool. By integrating a variety of elements together, it provides a **holistic beginning to end perspective for the project** development schedule. It is also an effective way of capturing the combined design and shipbuilding knowledge and processes, so they can be continuously **improved, updated, and used as training tools.**

**A Build Strategy effectively concentrates traditional meetings that bring all groups involved together evaluate and decide on how the ship will be redesigned, procured, constructed, and tested before any tasks are commenced or any information is "passed on."**

The objectives of the Build Strategy Document are as follows:

- 1 To identify the new vessel.
- 1 To identify the design and features of the new vessel.
- 1 To identify contractual and management targets.
- 1 To identify departures from the shipyard's shipbuilding Policy.
- 1 To identify constraints based on the new vessel being designed/constructed particularly with reference to other work underway or envisaged.
- 1 To identify what must be done to overcome the above constraints.

The last objective is particularly important as decisions taken in one department will have

implications for many Others. This means that effective interdepartmental communication is vital.

The very act of developing a Build Strategy will have benefits due to the fact that it requires the various departments involved to communicate and to think rationally about how and where the work for a particular contract will be performed. It will also highlight any potential problems and enable them to be addressed well before the "traditional" time when they will arise.

If a Shipbuilding Policy exists for the company, then it should be examined **in order to ascertain if a** ship of the type under consideration is included in the preferred product mix. If such a ship type exists then certain items will already have been addressed.

These items include:

- l outline build methods
- l work breakdown structure,
- coding,
- l workstations,
- l standard interim products,
- l accuracy control,
- l ship definition methods,
- l planning framework,
- l physical resources at shipyard, and
- human resources.

One thing which is unique to any new ship order is how it fits in with the ongoing work in the shipyard. The Current work schedule must be examined in order to fit the ship under consideration into this schedule. key dates, such as cutting steel, keel laying, launch and delivery will thus be determined.

Using the key dates other events can be planned. These events are:

- l key event program,
- l resource utilisation,
- material and equipment delivery schedule,
- l material and equipment ordering schedule,
- l drawing schedule,
- l schedule of tests and trials, and
- l stage payment schedule and projected cash flow.

Once the major events and schedules are determined they can be examined in detail to expand the information into a complete build strategy. For example, the event program can be associated with the work breakdown to produce planning Units and master schedules for hull, blocks, zones, equipment units, and systems.

The Build strategy Document should be used by all of the department listed above, and a formal method of feedback of problems and/or proposed changes must be in place so that agreed procedures cannot be changed without the knowledge of the responsible person. Any such changes must then be passed on to all holders of controlled copies of the build Strategy.

The Build Strategy is used to facilitate and strengthen the communication links. It should bring Up front and be used to resolve potential conflicts between departments in areas of design details, if a manufacturing process, make by decisions and in the delivery goals.

A Build Strategy can be used as an effective people empowerment tool giving Participants the opportunity to work out all their needs together in advance of performing the tasks.

The intent of a Build Strategy is to disseminate the information it contains to all who can benefit from knowing it. Throughout this report it is described as a hard copy document but today it could well be electronically stored and disseminated through local area network stations.

Producing a Build Strategy Document will not guarantee an improvement in productivity, although, as stated earlier, the process of producing the document will have many benefits. Full benefits will only be gained if the strategy is implemented and adhered to.

Positive effects of the Build Strategy approach are two-fold

- During production managers and foremen have a guidance document which ensures that they are fully aware of the construction plan and targets, even those relating to other departments. This reduces the likelihood of individuals making decisions which have adverse effects in other departments. Although often quoted by shipyards as being the reason for a Build Strategy, the benefits accruing from this are not major.
- l Prior to production, the use of the Build Strategy approach ensures that the best possible overall design and production philosophy is adopted crucial Communication between relevant departments is instigated early enough to have a significant influence on final costs. It is therefore the structured, cross-discipline philosophy which provides the downstream reductions in costs, and this is the major benefit

A yard which develops a strategy by this method will gain all the advantages whether or not a single

Build Strategy Document is produced. However, the imposition of the requirement for a single document should ensure that the development of the strategy follows a structured approach.

Perhaps the single most beneficial aspect of a Build Strategy is, that by preparing one, the different departments have to talk to each other as a team at the right time. A Build Strategy is a "seamless" document. It crosses all traditional department boundaries. It is an important step in the direction of the seamless enterprise. The most evident benefit is improved communication brought about by engaging the whole company in discussions about project goals and the best way to achieve them. It eliminates process/rework problems due to downstream sequential hand-over of tasks from one department to another by defining concurrently how the ship will be designed and constructed.

Some of the advantages mentioned by users of the Build Strategy approach are:

- helps prioritize work,
- serves as an effective team building tool,
- requires that people share their viewpoints because they need to reach a consensus,
- places engineers face to face with the customers - purchasing, production, test, etc.,
- expands peoples view of the product (ship) to include such aspects as maintenance, customer training, support service, etc.,
- fosters strong lateral communication,
- saves time through concentration on parallel versus sequential effort,
- facilitates resolution of differences and misunderstandings much earlier,
- greatly improves commitment ("buy in") by participants and the effectiveness of the hand-over later,
- serves as a road map that everyone can see and reference as to what is happening,
- facilitates coordinated communication, and
- develops a strong commitment to the process and successful completion of the project.

There are a few disadvantages mentioned by users, such as:

- effort and time to prepare the formal Build Strategy document,
- total build cycle appears longer to some participants due to their earlier than normal involvement,

- cross functional management is not the norm and most people currently lack the skills to make it work,
- experts who used to make independent decisions may have difficulty sharing these decisions with others in developing the Build Strategy, and
- a Build Strategy describes the complete technology utilized by a shipyard and if given to a competitor, it could negate any competitive advantage.

However, the users felt that the advantages greatly outweigh the disadvantages.

## PERFORMANCE OF THE PROJECT

Although it was known that a number of U.S. shipbuilders have utilized Build Strategies, it was not known how many and how effective they were.

A number of shipyards and the U.S. Navy believed in the benefit of the Build Strategy approach and this project was undertaken to accomplish the following objectives:

- To determine, for a number of U.S. shipyards involved in building the selected ship types, capabilities and limitations, and to classify them into common U.S. industry criteria.
- To determine how many U.S. shipbuilders currently use formal documented Build Strategies.
- To familiarize U.S. shipbuilding personnel with the Build Strategy approach, requirements, and benefits.
- To determine U.S. shipyard perceived need for a formal Build Strategy.
- To prepare a generic Build Strategy that can be used by U.S. Navy program office during concept, preliminary, and contract design, as well as U.S. shipyards, as the basis for the Build Strategy for a specific project.
- To prepare specific examples of the use of the generic Build Strategy for two selected ship types.
- To provide a final report on the findings of the shipyard survey on the use of formal Build Strategies, the perceived requirements, shipyard capabilities and limitations and how they were used/incorporated into the generic Build Strategy.

## SELECTION OF SHIP TYPES

Four ship types were offered as potential examples to the Panel Project Team, namely;

- Destroyer,
- Fleet Oiler,
- RO RO, and
- Container.

The Team selected the fleet oiler and the container ship in January 1993. As the project developed and the industry interest shifted even more from military to commercial ships, a number of sources recommended that the fleet oiler example be changed to a products tanker. Therefore, the final examples that were selected to demonstrate the use of the Build Strategy Development framework were a 42,400 tonne DWT Product Tanker and a 30,700 tonne DWT Container/RO RO ship.

Attempts to get ship design information from U.S. sources, for ships of these types recently designed and/or constructed, were unsuccessful. Therefore, an A&P Appledore design for a products tanker and the MarAd PD-337 Commercial Cargo Ship (non-enhanced) design were used for the examples.

## QUESTIONNAIRES

BUILD STRATEGY and SHIPYARD CAPABILITIES AND LIMITATIONS questionnaires were prepared for distribution to U.S. and Canadian shipbuilders. Their purpose was to determine current understanding and use of the Build Strategy approach and to determine current capabilities and limitations regarding building of selected ship types so that "common capabilities and limitations" could be developed and used in the two Build Strategy examples.

Both questionnaires were sent to 22 private and Navy shipyards. Questionnaires were received back from three shipyards. The Build Strategy Questionnaire was completely filled out in all three cases. The Shipyard Capability and Limitation Questionnaire was only completely filled out by one shipyard, with the other shipyards completing from 30 to 50 percent. Only one of the shipyards that responded to the questionnaires was willing to meet with the project team. Two other shipyards agreed to a team visit during telephone calls to solicit support for the project. The Build Strategy Questionnaires were also completed for two shipyards that were visited but had not completed the questionnaires.

All five shipyards responding to the Build Strategy Questionnaire were familiar with the Build Strategy approach. Only one had never prepared a Build Strategy document, although even that shipyard did prepare many of the listed content components and was of the opinion that it was not worth the effort to produce a single Build Strategy document.

There were wide differences in the need for many of the listed content components to be in the Build Strategy document. However, 18 out of 51 components were identified by at least four shipyards, and another 11 components by at least three shipyards. These 29 components were identified as Build Strategy "recommended" components. Two components in the Construction Data group, namely: Number of Plate Parts and Number of Shape Parts, were considered unnecessary by all five shipyards. They will not be included in the Build Strategy Document. The remaining 20 components were identified as "optional".

The lack of response made it impossible to determine common capabilities and limitations. However, the following findings are presented:

- Two shipyards have existing Marketing Departments which are involved in Market Research. Interestingly, they both have only been involved in Navy or government contracts during the past decade.
- One shipyard has a central planning and scheduling department, the others have a Master Planning Group that integrates the planning and scheduling of the various departments.
- Two shipyards have separate Material Planning/Control Groups and all three shipyards that responded to the questionnaire use material coding MRP II or similar systems.
- Only one shipyard has a complete in house engineering capability. Both the other shipyards subcontract most of their engineering to marine design agents.
- Two shipyards use CAD concurrent engineering, production oriented drawings, standard engineering procedures and engineering standard details.
- All three shipyards have complete in-house lofting capability that are part of the engineering department.
- Two shipyards have Manufacturing Industrial Engineering groups that are part of the Production Department.

- Engineering in all three shipyards is functionally organized into the traditional hull, machinery and electrical although their work is prepared for block construction and zone outfitting.
- Two shipyards use self-elevating, self-propelled transporters up to 250 ton capacity, and both self and non-elevating trailers from 50 to 80 ton capacity. Fork lift trucks from 1 to 14 ton capacity are used for general material handling.
- All three shipyards claim to use block construction, zone outfitting and packaged machinery units. They all claim to use Accuracy Control for structure and one shipyard uses it for piping, ventilation and electrical components.
- All three shipyards have state of the art painting capabilities.

#### **U.S. SHIPYARD VISITATION**

The project team visited BethShip, Avondale Shipyards and NASSCO. Each visit lasted a minimum of four hours with one taking six hours. A proposed agenda was sent to each shipyard prior to the meetings, along with a number of additional questions which would be asked during the visit. The project team first presented background information on the project, such as description, objectives, and approach. Then the purpose of the meeting was presented, which was to discuss face to face the questionnaire responses and clarify any questions. It was also to see what each shipyard had done, and was doing, with regard to Build Strategy. In addition, the Shipbuilding Technology Office of the Naval Surface Warfare Center at Carderock, Maryland was visited. The purpose of this visit was to learn about the Generic Build Strategy activity being worked on for the Mid Term Fast Sealift Ship (MTFSS) program. The purpose of the meeting was to determine how the two projects could and should interact. The Navy reported that there was considerable confusion in the industry because of identical project titles, and concern regarding the relationship of the SP-4 Panel Build Strategy project and the U.S. Navy's Mid Term Fast Sealift Ship program. Questions being asked ranged from "Are they connected?" to "How are the two projects going to be differentiated?" There is no contractual connection. The MTFSS program is interested in using the Build Strategy approach for one specific ship in a number of shipyards to reduce the time taken from contract award to delivery of the ship.

The SP-4 project is interested in showing many shipyards how to use the Build Strategy approach for any ship type. The visit was most beneficial in determining this difference and resulted in agreement that it was necessary to differentiate between the two projects to the maximum extent possible. It was mutually decided to rename the SP-4 project and further, to concentrating entirely on commercial shipbuilding and ship types. It was decided to clearly differentiate between the two projects by changing the title of the SP-4 project to BUILD STRATEGY DEVELOPMENT.

All shipyards and the Shipbuilding Technology Office were very cooperative and generous in the giving of their time and sharing of their experiences and information.

All three shipyards were familiar with the Build Strategy approach and had prepared a number of Build Strategies in preparation of bids. Ship types involved were container ship and product tanker. Two had used Build Strategies for at least one complete design/build cycle. Ship types involved were container, sealift conversion and T-AGS.

The departments having the major responsibility for the Build Strategy Development were under Production in two shipyards and part of Advanced Product Planning and Marketing in the other shipyard.

All three shipyards were committed to using the Build Strategy approach in continuing greater scope. This was entirely based on their own perceived needs/benefits and was not being driven by external demands or pressure.

The project team was able to review recent Build Strategies at each shipyard and was impressed by the level at which they were being used. Build Strategy size ranged from 100 to 300 pages. Typical effort ranged from 400 to 2000 man hours. However, it was pointed out that most of the effort would be required in any case. It simply was being performed earlier, up front, in a formal and concurrent manner. Based on this, the additional effort to prepare a Build Strategy is likely to be about 400 hours. Obviously, the first time it is done, the additional effort may be considerably more as the new approach must be learned in a team environment and many traditional barriers broken down.

By this review and discussion of the Build Strategies, it was possible to determine the items which were considered by the shipyards to be essential, which items were optional, and what should not be included in the Build Strategy document.

The project team emphasized that it was necessary for each shipyard to have a documented Shipbuilding Policy on which to base their Build Strategies.

Otherwise, each Build Strategy must contain the required policy components.

The shipyards had a number of concerns and emphasized the following requirements:

- Build Strategy document should not be so structured that it discourage innovation or the introduction of improved methods or facilities.
- It should not attempt to tell shipyards how to prepare drawings, build ships, define or limit block size or dictate required production information.
- It should incorporate need for design for producibility and be a guide for continuous improvement and TQM.
- The Build Strategy document and examples of its use should be based entirely on commercial ships of the type likely to be built in the U.S. in the foreseeable future.
- It should not address military ships of any type.
- The Build Strategy document must treat all components of the design, build, and test process with equal attention. So often the "simpler" or "better known" front end design and production decisions are more than adequately treated, but the back end processes, such as system tests and compartment check off, are given minimum consideration in a Build Strategy.
- The two examples of the Build Strategy document use should emphasize the ship type major differences and their impact on the Build Strategies.
- The project should emphasize the benefits of the formal Build Strategy approach. In doing this an attempt should be made to determine which world class shipbuilders use the Build Strategy or similar approaches.
- The project should also clearly describe the pre-requisites that a shipyard should have or develop before undertaking a Build Strategy to ensure the best chance of an effective Build Strategy being developed and implemented.
- The use of preliminary and detailed Build Strategies should be clearly described.
- The project should provide documentation that is suitable for use as an educational tool.

Because of the reluctance of most shipyards that were contacted to share the detailed information requested by the Shipyard Capabilities and Limitations Questionnaire, no renewed attempt was made to obtain this information during the visit. Instead, each

shipyard visited was asked what were their two or three major limitations. All three shipyards mentioned crane capacity. They would all like to erect larger blocks than currently possible. One shipyard would like to increase crane capacity throughout the fabrication and assembly shops, as well as for block erection on the ways or in the dock. Another shipyard would like to have more covered (out of the weather) buildings for assembly and block construction. Finally, one shipyard mentioned that its major limitation was timely engineering.

## **U.S. SHIPYARD COMMON ATTRIBUTES**

As previously mentioned, due to lack of response to the Shipyard Capabilities and Limitations Questionnaire, it was not possible to determine U.S. shipyard common attributes which could be used in the Build Strategy Document. In order to have a basis on which to prepare the project Build Strategy Document and examples of its use, a hypothetical shipyard was defined by the project team. The hypothetical shipyard represents no existing U.S. shipyard but rather attempts to reflect some of the facilities and capabilities of a typical U.S. shipyard that would be interested in competing in the world commercial ship market. It does not reflect the lowest common capabilities.

## **FOREIGN SHIPYARD VISITATION**

Eight foreign shipyards were contacted, but only four responded and three of them agreed to a visit.

Visits to the three foreign shipyards were made in June and July, 1993. The shipyards were Ferguson's in Port Glasgow, Scotland, a successful small shipbuilder; Odense Steel Shipyard in Denmark, a successful large shipbuilder reputed to be one of the best shipbuilders in the world today; and Astilleros Espanoles in Spain, another successful large shipbuilding group which has utilized many of the NSRP project publications to assist them in their improvement program.

All shipyards visited gave outstanding support in time and effort to the team, and their hospitality was exceptional. They were most open in showing and describing their facilities, processes, goals, and problems, and all stated that their willingness to participate in projects to help the U.S. shipbuilding industry improve was based on the belief that everyone benefits from an open exchange of technology, a sharing of problems, and the development of solutions for their resolution.

Ferguson's does prepare a Build Strategy for each contract. They cover most of the recommended items in the study proposed Build Strategy Document List. Most of the optional items are omitted, although they do include budgets. Build Strategy with budgets are given restricted distribution. The Production Engineering Group has the responsibility to prepare the Build Strategies with input from other groups/departments.

Ferguson's Build Strategy is relatively simple (that's how they like it), but even with their small size they still see and achieve benefits from using the Build Strategy approach. Ferguson's uses previous Build Strategies as the basis for new Build Strategy.

Ferguson's approach was to accept mid-1980 facilities and to concentrate on using their people more effectively through integrated processes.

Odense Steel Shipyard (OSS) has excellent facilities with up to date equipment and processes. They have an extensive ongoing facilities improvement program. They are not satisfied with any phase of their operation and are always seeking continuous improvement. They are currently building today what they did in the past with 40% of man hours. OSS believes productivity is the key to future success in global shipbuilding. They have a goal of 6% annual productivity improvement.

Typical build cycle is 12 month with 3 month in the building dock, one month outfitting and 3 weeks deck trials and sea trials. Sea trials are normally 3 days and once the ship leaves the shipyard for sea trials it does not return to shipyard.

OSS does not use the Build Strategy approach, but has a planning system that covers most of the Build Strategy components and recognizes the need to communicate this information in a formal manner to the many users in a shipyard. OSS was not aware of the Build Strategy approach. However, the way they prepare and formally document and distribute their planning documents achieves some of the same objectives. OSS does have a long term business plan and the Phase I part of their planning process is similar to the Shipbuilding Policy. Their planning is totally integrated. OSS has always used standard processes and standard details to the maximum extent. They are an effective part of OSS high productivity in all departments and processes. OSS has very up to date capabilities and is in the fortunate position of having no known limitations for the foreseeable future.

Astilleros Espanoles is a grouping of diverse shipyards covering all sizes of commercial ships and offshore vehicles/rigs. They have a central office in Madrid. This central group performs much of the business planning and setting of each shipyard policy. However, at the meeting with representatives of all

shipyards in the group, and at meetings at Sestau and Puerto Real Shipyards, the enthusiasm of individual managers for continuous improvement, including the use of a Build Strategy approach, was very clear.

Each shipyard has its own 5 year plan covering goals, productivity, ship types and employees. A major point in their use of Build Strategy is the development of a catalog of interim products for each shipyard. Build Strategies were reviewed in two shipyards. They covered most of the recommended items in the study proposal Build Strategy Contents List. In addition, they added interesting information about the ship owner, his existing fleet and operations. The study proposed Build Strategy Contents List was modified to incorporate this additional item as an option.

Astilleros Espanoles shipyards cover the range from old shipyards to relatively new facilities, but in all cases they have had significant modernization in the last few years, some of which is still underway. Only one shipyard acknowledged any limitations, and that was the clear width of a bridge through which its ships had to pass to get to the sea.

All of the shipyards visited stated that improvement in productivity was the key to survivability and future success in the global shipbuilding market place.

## **BUILD STRATEGY DOCUMENT CONTENTS LIST**

A contents list, shown in Table III, was developed for the Build Strategy Document from the questionnaire responses, as well as from shipyard visit discussion. The actual Build Strategy Document and the two examples followed this contents list. An introduction outlining the purpose of the Build Strategy Document, its suggested distribution in a shipyard and the prerequisites for a successful Build Strategy was also provided.

**TABLE III  
PROPOSED BUILD STRATEGY  
DOCUMENT CONTENTS**

**R IS RECOMMENDED  
O IS OPTIONAL**

**1: INTRODUCTION**

1.1 Purpose of Document	R
1.2 Build Strategy Document Prerequisites	R
1.3 Distribution	R
1.4 Summary	R

**2: VESSEL DESCRIPTION**

2.1 General Description & Mission	R
2.2 Principal Particulars	R
2.3 Special Characteristics & Requirements	R
2.4 Comparisons/Differences From Previous Vessels	R
2.5 Applicable Regulations & Classification	O
2.6 Owner Particulars	
2.6.1 Background	O
2.6.2 Fleet	O
2.6.3 Past Relationship	O
2.6.4 Competition	O

**3: CONTRACTUAL**

3.1 Contractual Dates & Time Constraints	R
3.2 Payment	O
3.3 Liquidated Damages & Penalties	R
3.4 Cancellation	O
3.5 Drawing Approval	O
3.6 Construction Inspection	O
3.7 Trials	O
3.8 Quality	R

**4: DESIGN & ENGINEERING**

4.1 Strategy & Scope	
4.1.1 General	R
4.1.2 Changes to Ship Definition Strategy	R
4.1.3 Modeling & Composites	R
4.2 Key Drawings	R
4.3 Production Information requirements	
4.3.1 CAM Information	R
4.3.2 Manufacturing Information	R
4.3.3 Parts Listings	R

4.3.4 Installation Drawings	R
4.3.5 Installation Procedures	R
4.4 Design & Engineering Schedule	
4.4.1 Schedule	R
4.4.2 Resourcing & Utilization	O
4.4.3 VFI Schedule	R
4.5 Datum's & Molded Definition	O
4.6 Design Standards	R
4.7 Functional Space Allocations	R
4.8 Detail Design Guidelines	
4.8.1 Steelwork	O
4.8.2 Machinery	O
4.8.3 Pipework	O
4.8.4 Electrical	O
4.8.5 Joinerwork	O
4.8.6 Paintwork	O

**5: PROCUREMENT**

5.1 Master Material List	O
5.2 Master Equipment List	O
5.3 Material Procurement Strategy	O
5.4 Procurement Schedule	R
5.5 Critical/Long Lead Items	R

**6: PLANNING & PRODUCTION**

6.1 Strategic Planning	
6.1.1 Key Event Program	R
6.1.2 Resourcing & Utilization	O
6.1.3 Changes to Shipbuilding Policy	R
6.1.4 Required Facility, Tooling & Equipment Upgrade	R
6.2 Work Breakdown	
6.2.1 Work Breakdown Structure	R
6.2.2 Coding	R
6.3 List of Planning Unit	
6.3.1 Hull Blocks	R
6.3.2 Zones	R
6.3.3 Equipment Units	R
6.3.4 Systems	R
6.4 Master Schedules	
6.4.1 Hull Blocks	R
6.4.2 Zones	R
6.4.3 Equipment Units	R
6.4.4 Systems	R



6.5 Hull Production Strategy		
6.5.1 Preliminary Process Analysis	O	
Integration of Outfit		
Process Analysis By Block		
6.5.2 Non Standard Interim Products	O	
6.5.3 Build Location & Launch Condition	R	
6.5.4 Erection Schedule	R	
6.6 Machinery Space Outfit Strategy		
6.6.1 Equipment Units	R	
6.6.2 On Block Outfitting	R	
6.6.3 On Board Outfitting	R	
6.7 Accommodation Outfit Strategy	R	
6.8 Cargo & Other Space Outfit Strategy		
6.8.1 On Block Outfitting	R	
6.8.2 On Board Outfitting	R	
6.9 Painting Strategy		
6.9.1 Outline Paint Specification	O	
6.9.2 Pre-Painting	R	
6.9.3 Primer Repair Strategy	R	
6.9.4 Unit/Block Painting Strategy	R	
6.9.5 Zone Painting Strategy	R	
6.9.5.1 Machinery Spaces		
6.9.5.2 Outside Shell and Decks		
6.9.6 Special Considerations	R	
6.10 Sub-Contract Requirements		
6.10.1 Bought-In Items	R	
6.10.2 Use of On-Site Sub-Contractors	R	
6.11 Productivity		
6.11.1 Productivity Targets	R	
6.11.2 Comparisons/Differences From Previous Vessels	R	
6.12 Temporary Services		
6.12.1 Staging Plan	R	
6.12.2 Access & Escape Plan	O	
6.12.3 Power & Lighting	O	
6.12.4 Weather Protection	O	
<b>7: ACCURACY CONTROL MANAGEMENT PLAN</b>		
7.1 System Critical Dimensions & Tolerances	R	
7.2 Interim Product Critical Dimensions & Tolerances	R	
7.3 Sampling Plan	O	
7.4 Special Procedures	O	
7.5 Jigs & Fixtures	O	
7.6 Hot Work Shrinkage		
7.6.1 Use of Extra Stock	O	
7.6.2 Shrinkage Allowances	O	
7.6.3 Distortion Control	O	
<b>8: TEST &amp; TRIALS</b>		
8.1 Test Planning		
8.1.1 Strategy		R
8.1.2 Schedule (High Level)		R
8.2 Pre-Completion Testing		
8.2.1 Pre-Survey & Dry Survey		O
8.2.2 Pipe Pre-Testing		O
8.2.3 Equipment Unit Pre-Testing		O
8.3 Tank Test Schedule		R
8.4 Equipment Unit Test Schedule		R
8.5 Pipe Unit Test Schedule		R
8.6 Zone Close-Out Strategy		R
8.7 Principal Trials Items		R
<b>9: PERSONNEL</b>		
9.1 Industrial Relations Aspects		
9.1.1 Design		O
9.1.2 Sub-Contract		O
9.2 Training		O
9.3 Project Organization		
9.3.1 Shipyard Organization Charts		R
9.3.2 Client's Organization Charts		R
<b>10: WEIGHT CONTROL</b>		
10.1 General		
10.2 Outline Procedure		R
10.3 Departmental Responsibilities		R

## **ACKNOWLEDGMENTS**

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Both questionnaires were jointly developed by A&P Appledore International Ltd and Thomas Lamb. However, without the participation of the shipyards who took the time to respond to the questionnaires and those that agreed to allow the project team to visit and discuss the subject further, this report would have no value. Their contributions are acknowledged with appreciation.

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# Generic Build Strategy - A Preliminary Design Experience

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## ABSTRACT

From the very inception of the Preliminary Design phase of the U.S. Navy's new amphibious assault ship, which at the time was designated only as the LX, there has been an emphasis on generating a design which is producible; one that requires a minimum of redesign by the building yard and which can be built efficiently using modern ship construction techniques. This emphasis resulted in establishment of a Producibility Task Manager as a member of the LX Preliminary Design Team and in the creation of a Product-Oriented Design And Construction (PODAC) Working Group. The functions of this Group were to mimic a shipyard production planning effort and to interact with the Design Team on a regular basis. This paper describes the results of their efforts, including the development of a Generic Build Strategy (GBS) and numerous Design for Producibility improvements during the LX Preliminary Design Phase.

## NOMENCLATURE

The nomenclature used throughout this paper complies with that in use in most of the National Shipbuilding Research Program (NSRP) documentation and with that used in Reference 1. No attempt is made herein to describe elements of the Zone-Oriented construction processes or procurement processes used in current day shipbuilding, since these matters are thoroughly covered in numerous other NSRP documents.

## BACKGROUND

Use of a GBS has been proposed as a means to incorporate ship production considerations into the early stages of naval ship acquisition with the objective of reducing ship acquisition cost. Any world class organization developing and acquiring a new item requires the concurrent development of the product design and the process by which the product is fabricated and/or assembled. During the feasibility study, preliminary design and contract design phases of ship design, namely the early stages of ship acquisition, there are not only systems engineering benefits of having a GBS, but there are also potential benefits to program management efforts.

The Navy's early stage ship design management, recognizing that changes in the design process were necessary in order to respond to the changed ship construction methods used in the nation's shipbuilding yards, assigned a Producibility Task Manager to the team that was assembled to develop the Preliminary Design (PD) of the LX. His responsibilities included overseeing and driving design for production efforts as a part of general acquisition cost reduction efforts. Since an inherent part of designing a ship to be most producible is to have a reasonably good idea of how it will be built, one of the major tasks of the Producibility Task Manager was to develop a GBS. That is, in addition to emphasizing the need to design the ship to be more producible, it was necessary to provide the designers with a general idea of how the ship would likely be built. This build strategy would necessarily be

generic, in that it could not be oriented to the unique capabilities of any one of the several shipyards that would be expected to bid for the construction contract. Nevertheless, this generic build strategy was expected to reflect the actual current capabilities of U.S. shipyards in order to effectively evaluate the impact of design decisions on ship production and to leverage the design efforts towards a more producible and cheaper acquisition cost. This effort was the first application of the concept of development and use of a GBS for a U. S. Navy in-house early stage ship design.

## **PODAC WORKING GROUP**

The LX Preliminary Design effort was initiated in the second quarter of FY '93 at a Navy collocated design site. This phase of the design was divided into five design iterations, with the last iteration of the design to be completed during the first quarter of FY '94. During PD, no shipbuilders were under contract to support development of a GBS, so, under the leadership of the Producibility Task Manager, a simulated ship production department was assembled using experienced non-shipyard-affiliated ship production experts. This "surrogate shipyard", more formally called the Product-Oriented Design And Construction (PODAC) Working Group, was established in June 1993 to mimic a shipyard planning effort, and to interact with the LX ship designers and engineers during PD. This group was comprised of members who had firsthand knowledge of the amphibious ship construction process and who possessed an understanding of modern (advanced) ship construction practices.

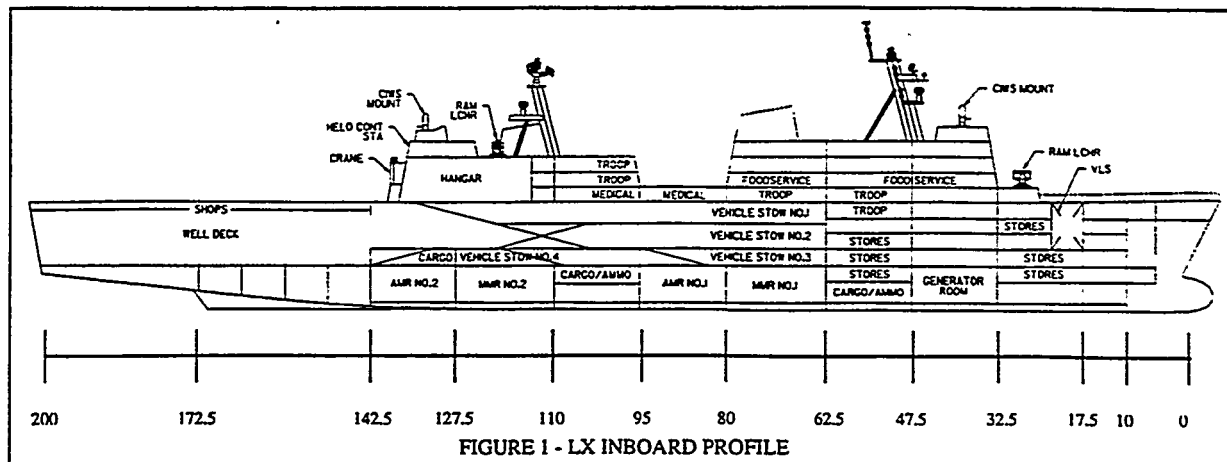
One function of the PODAC Working Group was to interface with the ship design team during PD, and, by introducing ship design for production concepts early within the various design disciplines, to guide the achievement of

a more production-friendly design. Navy ship designers, especially during the early stage design, are typically isolated from production facilities, working either at a design agent's office or a Navy collocated design site, under short deadlines and to stringent operational requirements. The PODAC Working Group was tasked to enhance the design team's capabilities by "thinking" for the design team as a shipyard would think if the design were being done at the shipyard.

From the inception of the early design stage effort it was intended that shipbuilders be given the opportunity to participate in evaluations of the Contract Design (CD) of the ship, through the use of on-site representatives and funded support for design evaluations, specification reading sessions and studies of detailed aspects of the design as it proceeded. It was intended from inception of the design that the GBS developed by the PODAC Working Group would be made available to the shipbuilders for their critical analysis, suggested changes and identification of any specific aspects of that strategy which would degrade their ability to compete equally for the shipbuilding contract and build the ship for minimum cost.

It has never been the Navy's intention to impose the build strategy upon the shipbuilder. One of the primary purposes of the involvement of the shipbuilders during the CD process was to identify aspects of the design, that would negatively impact the competitive aspects of building it. The primary purpose of the GBS was to help ensure that the design generated through CD would be capable of being built efficiently without major redesign efforts by the successful shipbuilding contractor.

The PODAC Working Group accomplished three primary functions during the Preliminary Design phase. They developed a Generic Build Strategy, which was used as a guide in



evaluating and revising the location and configuration of spaces in the General Arrangement Plan and in the structural design of the ship. They provided Design for Producibility guidance to the system designers in developing system details and arrangements that would enhance the producibility of the systems without negative impacts on maintainability or operability of the systems. In addition, the team provided some cost estimates based on work content instead of weight, as guidance to NAVSEA cost estimators in assessing the results of design modifications. The approach to each of these three efforts and the major results are analyzed in the following sections.

## DESCRIPTION OF THE SHIP

The LX (since designated the LPD-17) is the U.S. Navy's next generation Amphibious Transport Dock ship with a primary mission to embark, transport and debark marine landing forces in assault by helicopters, LCACs, and assault amphibious vehicles. It is intended to be a functional amphibious lift replacement for 41 ships of the LKA 113, LPD 4, LSD 36 and LST 1179 Classes. In early PD it was established that the design was to be hybrid metric.

Figure 1 shows the PD inboard profile of the LX. Frames are numbered from the bow aft, based on the number of meters from the forward perpendicular. Thus Frame 100 is amidships. At the end of PD, the LBP and LOA of the ship were 200m and 208.4m, respectively, with a beam of 31.9m.

## GENERIC BUILD STRATEGY DEVELOPMENT

### General

The major part of the PODAC Working Group's efforts were directed toward the identification of design features that would enhance the ability of any prospective shipbuilder to build the ship in a logical fashion using modern Zone-Oriented construction techniques. Since significant savings can be realized during Detail Design if a shipyard receives a Contract Design arrangement that recognizes where construction joints will be located and ensures that minimum interferences with those welding paths are created, a Generic Build Strategy was developed by the PODAC Working Group. This strategy was considered *generic* in that it was intended to result in a design that would be capable of being built efficiently by any of the potential

builders without major changes in their production facilities.

The first step taken in the development of a build strategy for the LX was to identify the major zones which would likely control the construction process. The inputs to this process were the first draft of the General Arrangement and Midship Section drawings. The General Arrangement Drawing included the Inboard Profile shown in Figure 1, an Outboard Profile and plan views of each deck.

These documents were used to identify the major zones of the ship and then, with a set of block break criteria established by the team, to identify the block breaks. A block numbering sequence was developed that related each block to a location in the ship. With the block breaks identified, a notional block erection sequence was identified. By putting a time scale on that sequence and utilizing historical time frames between block erections, an erection schedule was developed. A list of major equipment was developed. The block into which each piece of major equipment was to be located was determined. By correlating the lead time for the various elements of the equipment procurement process with the block erection schedule, it was possible to develop an equipment installation schedule and a first cut at the dates by which major equipment would have to be ordered. This information could be used to identify what long lead equipment, if any, would have to be ordered before the shipbuilding contract is awarded in order to minimize the time of the shipbuilding process. A more detailed description of each of these elements of the Generic Build Strategy follows:

### **Zone Identification**

In commercial ships the machinery space is normally a single space located aft, the accommodations (for the small number of crew

members) are all located above the main deck in a separate deckhouse and the rest of the ship is configured for the type of cargo that the ship is to carry. It is common practice to identify each of these portions of the ship as a separate zone; namely the Machinery Zone, Accommodations Zone and Deck Zone. Each of these three major zonal volumes of the **ship** entails significantly different functions, complexity of construction and material ordering requirements, as a result of different design requirements. Therefore, it is customary to treat each of them as a separate zone, and to assign to each, separate design teams who are familiar with the peculiarities of construction of that zone.

The entire ship is considered as a fourth zone, since certain work can be done most efficiently onboard the ship before or after it is being erected. Where the work in a particular area of the ship is more complex than that in another area of the ship, that particular part of the ship may be treated as a separate zone or subzone.

In military ships, where, largely for survivability reasons, there normally are multiple machinery spaces, and where accommodations (for much larger crews) are spread throughout the ship, the identification of the basic three types of zones is not as straightforward. Zones can be identified, but several functions may exist within each zone. In the case of the LX, with the configuration shown in Figure 1 as a given, the PODAC team identified the following zones.

**Machinery Zone.** The machinery spaces contain many large, heavy pieces of equipment arranged in relatively dense configurations, involving major distributive system interfaces. On the LX, the Machinery Zone was taken to be the volume extending from Frame 62.5 to 142.5 longitudinally and from the keel to the 01 Level vertically. This volume includes the

two Main Machinery Rooms and the two adjoining Auxiliary Machinery Rooms.

Deckhouse (Accommodations) Zone. All volume above the 01 Level was treated as a single zone. Although there are few accommodations in this volume, it was treated as a separate zone, primarily for convenience, since it is above the strength deck. For this ship; this zone is not significantly different in most production considerations than the rest of the ship outside the Machinery Zone.

Hull Zone. Although the rest of the ship below the 01 Level would therefore be considered the Hull Zone, on the LX, because the Machinery Zone separates the forward portion of the ship from the stem, the after portion of the ship was treated as a separate zone. The forward portion of the ship was treated as two separate zones because the work in the bow area, forward of the bulkhead at Frame 17.5, is significantly more difficult to construct than the volume between Frames 17.5 and 62.5.

SubZones. Each of the zones on the ship was further subdivided into subzones, based primarily upon the location of transverse bulkheads, recognizing that these bulkheads would be used ultimately to establish the boundaries of hull construction blocks and this subdivision would be used in the block numbering sequence.

Zone Numbering. The zone from the bow to Frame 17.5 (a Hull Zone) was identified as Zone 1000. Two subzones were identified as 1100 and 1200; the division being at Frame 10.

The volume between Frames 17.5 and 62.5, from the keel to the 01 Level, was identified as Zone 2000, with Subzones 2100, 2200 and 2300 separated by Frames 32.5 and 47.5. Although Zone 2000 includes a generator space, the configuration of this portion of the ship is sufficiently different than that of the volume

forward of it and of the portion aft, that it was treated as a separate zone.

The Machinery Zone was designated Zone 3000, with Subzones 3100, 3200, 3300, 3400 and 3500 separated by the transverse bulkheads at Frames 80, 95, 110, and 127.5.

Zone 4000 extends from just aft of the bulkhead at Frame 142.5 to the stem and includes cargo carrying and line handling areas. It is separated into Subzones 4100, 4200, 4300 and 4400 by transverse bulkheads at Frames 157.5, 172.5 and 187.5.

Zone 6000 is comprised of the volume above the 01 Deck. In an earlier version of the ship's topside conjunction there was a Zone 5000. An arbitrary decision was made to leave the 6000 zone designator unchanged when Zone 5000 was eliminated

#### Block Identification Considerations

Because modern shipbuilding techniques involve construction and outfitting of the ship in major three-dimensional assemblies conventionally called blocks, one of the most essential elements of a build strategy is the identification of the boundaries of each of those blocks. All elements of the entire construction, outfitting and ship erection sequencing (the primary elements of a build strategy) are built around the definition of the blocks. For a ship design to be a producible design, the arrangement of spaces and locations of equipment must take into account the block break locations.

This is also the area where individual shipyards, with different facilities or different construction philosophies, may have significant differences in approach. The ability to create a generic build strategy that does not penalize specific shipyards is dependent upon selecting locations for block breaks that are

logical and based upon actual current ship-building practices and shipyard capabilities.

The PODAC Working Group recognized the following elements as affecting the definition of block break locations and block sizes:

- . To provide the structural stiffness required for transporting and lifting blocks, it is normal for one end or side of a block to be located close to, but not at the location of a transverse or longitudinal bulkhead or deck. To facilitate the welding of this end or side to the adjoining block during erection, the erection joint is located roughly 300 mm (6 -12 inches) from the bulkhead or deck and the stiffeners are located on the opposite side of the bulkhead or deck from the erection joint.

Normally, one end or side of a block is "hard," meaning that the stiffeners are welded to the plate all the way to the extreme end of the block while the other end or side is "soft" with the stiffeners remaining unwelded for the last half meter (say 18 inches). This allows the stiffeners of the "soft" end to be aligned to those of the adjoining block more readily during erection. The "hard" side normally is the side near the bulkhead or deck of course.

- . To facilitate as much installation of under-deck items such as pipe hangers, piping, electrical wireways, ventilation ducting, etc. as possible prior to erection, the block breaks are normally made roughly 200 mm (3 -6 inches) above a deck. The completed assembly can then be turned right-side-up and landed in place on top of another block.

Given the above considerations, in defining block boundaries it is necessary to consider

- . Location of major longitudinal bulkheads and other major structures.
- . Transverse bulkhead spacing.
- . Length and width of plates available from steel manufacturers.

- Maximum weight and size of outfitted blocks which can be handled and transported in a yard.

- . Amount of pre-outfitting to be accomplished in the block before erection.

- An effective method of erecting the blocks.

## **Block Break Criteria**

The following criteria were established by the PODAC Working Group as standards, to be altered only when some particular characteristic of the structure or arrangement could be shown to override the producibility aspects of the construction sequence:

- . All block breaks would be above the deck and aft of a transverse bulkhead.

- . All stiffeners on transverse bulkheads would be located on the forward side of the transverse bulkhead, wherever practicable.

- . Blocks would extend from each major transverse bulkhead to the next.

- . Block widths would not exceed 10 meters.

- Block heights would be one deck high, except along the sides of the ship and in the bow, where space arrangements permit multiple deck high blocks.

## **Block Break Definition**

optimization of plate width or plate length was not actively considered in the development of the block break plan. Instead, the Group was confined to finding a logical block break scheme within the constraints of the design that had been developed to meet the operational requirements.



For this initial effort the most immediate concern was the distance between major subdivision bulkheads. Except for the Main Machinery Rooms (MMRs) this distance is 15 meters (approximately 49 feet); very near the maximum plate length traditionally available from steel manufacture without special orders. The MMR bulkhead spacing may require piecing of plate lengths, but this was accepted for the PD, awaiting further comment from shipbuilders during their CD participation. The major subdivision locations were established prior to and independent of the block break scheme outlined here, having been selected during the feasibility design stage.

Throughout PD no significant shell straking effort was undertaken, with the exception of locating the crack arrestor plating.

**Block Width Bottom Shell and Inner Bottom.** In the block break plan, the double bottom of the ship is generally broken transversely just inboard of each wing wall and 1.5 meters outboard of the CVK to accommodate the standard 3 meter plate width flat keel. At its widest point the distance between wing walls is 19 meters. Therefore, one inner bottom block is approximately 8 meters in width, while the other is 11 meters. These can be fabricated from combinations of plates of 2 meter width and 3 meter width.

**Block Width: Interior Decks.** For the decks above the inner bottom, each hull block includes the half width deck inside the wing walls and the bulkhead(s), stanchions and associated structure beneath the deck. The straking scheme and widths selected for plates are as described above.

**Side Block Dimensions.** The Well Deck and Vehicle Stowage Decks extend through two thirds of the ship length. As described later in the paper in the section on parallel shaping of the hull, the shape of the shell for virtually the entire length of the ship represents parallel sections of flat plate with identical cross sec-

tion. For much of this length the wing walls of the well deck and vehicle stowage decks are straight. Consequently, the block breaks along this entire length of hull are just inboard of the wingwall and just aft of the transverse bulkheads. Inmost of this length of hull, the blocks were selected to be two decks high, partly because tank structure and tank dimensions dictated the selection of block breaks in the lower portions of the area and partially because of the customary construction practices in U.S. shipyards.

### Block Numbering Scheme

Although a block numbering system is a relatively trivial concern, in that almost any consistent numbering system will meet the needs of the shipyard and certainly has no effect on the early stage design development the PODAC Working Group developed a four-digit numbering scheme for the blocks.

The first digit identifies the zone in which the block is located. (i.e. 2xxx for Zone 2000)

The second digit identifies the subzone in which the block is located. (i.e. 21xx for the first subzone in Zone 2000)

The third digit identifies the deck level of the topmost deck in the block. The Inner Bottom was identified as deck level 1, the 2nd Platform as level 2, the 1st Platform as level 3, 2nd Deck as level 4, and so on. For blocks which are more than one deck high, the highest deck level was used for numbering the block.

The fourth digit identifies the transverse location of the block with 1 being the inboard starboard block, 2 being the inboard port block, 3 being the outboard starboard block (since there were never more than two blocks on either side of centerline) and 4 being the outboard port block.

## Block Break Drawing

After identifying the block breaks by marking up the general arrangement drawings, an isometric drawing was prepared to provide a visual description of the results of the effort. The LX product model sub-division model was used as the basis for development of the block break plan. Using the criteria described previously, the LX was divided into 186 blocks; 7 in Zone 1000, 33 in Zone 2000, 95 in Zone 3000, 38 in Zone 4000 and 13 in Zone 6000.

## BLOCK ERECTION PLANNING

Having the blocks defined and numbered, the next step in the development of a building strategy is to produce the schedule by which the blocks will be erected at the building site. This effort is not critical for the development of a PD, but was felt to be of use for assessing where Navy resources might best be expended in additional design development.

### Block Erection Sequence

When developing the block erection schedule, the PODAC Working Group found it helpful to develop a notional block erection sequence. The technique used by the PODAC Working Group is described below, but is recognized as only one possible way to achieve the same objective.

A table, similar to that shown in Table I, was prepared. Each column represents one subzone of the ship. The subzone numbers were listed at the top of each column. In each column, all of the block numbers in that zone

were listed from top to bottom in the order in which they would be erected.

On a separate sheet, using the same general format, the sequence of joining each of the blocks was laid out. The numbers of the first blocks to be erected were placed in the top-most horizontal line, located directly below the subzone of which the blocks were a part. The numbers of the next blocks to be erected were placed in the next horizontal line, directly below their own subzone numbers. This process was continued working down the page in the order in which each set of blocks would be joined to the blocks in the preceding horizontal row. Table II illustrates the form of the table that was generated. A spacing of two lines was placed between sequential blocks in subzone 3300, from which the erection process initiated so that the fore and aft sequencing of block erection would not be obscured.

### Block Erection Schedule

The final step in the process of developing the block erection schedule is to evaluate the number of weeks required between each of the blocks in one horizontal line and the blocks in the next lower horizontal line, thus converting the vertical dimension on the page to a time scale. The scale can be measured in terms of weeks after erection of the first block or weeks before erection of the last block or both.

Since the overall time between erection of the first and last blocks is but one part of the total detailed design and construction period of a ship, estimates also must be made of the time span between Contract Award and the erection date of the first block and of the span from erection of the last block to delivery of the ship. The sum of these three values is the total ship construction duration that must be allowed for in a prospective ship owner's

# LX SUBZONE NOTIONAL BLOCK ERECTION SEQUENCE CHART


planning. It is then possible to convert the time scale on the block erection schedule to weeks before delivery or to weeks after contract award. Both of these sets of values are useful in acquisition planning.

## LONG LEAD EQUIPMENT SCHEDULE IMPACTS

Procurement of Long Lead Time (LLT) material is a significant part of the preconstruction effort in shipbuilding contracts. For the purpose of this study, equipment having manufacturing lead times of 12 months or more were considered LLT items.

The Navy's historical material data base maintained by NAVSEA Shipbuilding Support Office (NAVSHIPSO) was used to develop a list of the major equipment on the ship and, from that, to identify the LLT items. For planning purposes, worst case lead times based on historical data from recent amphibious assault ship construction programs, such as the LSD 44, were used.

The first step in developing the LLT schedule was to identify the block into which each item will be located. In cases where identical pieces of equipment are located in several blocks, each of those blocks must be included in order to determine which of them requires the earliest in-yard receipt. For each LLT item, an estimate was made of the time duration before or after block erection that the item must be ready, based on experience with past shipbuilding programs.

Estimates for durations of each of the following activities in the procurement cycle were made (further explanation of these activities is found in Reference 2):

1 Preparation of Requests for Quotation (by the shipyard),

. Preparation of offers (by vendors),

. Evaluation of offers, approval and negotiation (resulting in purchase order issue),

. Manufacturing lead time (including shipping),

1 Shipyard receipt inspection

1 Preparation for installation.

When the sum of these durations is subtracted from the block erection date (measured in months after contract award), a positive resultant means that the procurement process can begin after contract award. When the answer is negative, however, it means that the procurement process for the equipment must be initiated by the ship owner before the shipbuilding contract has been awarded. There are several options available to a ship owner to accomplish the procurement of such equipment, but it is important that this information be known as soon as possible so that the acquisition strategy can reflect this need.

The overall detailed design and construction schedule selected for the LX by the program office was such that no LLT material and no advanced procurement contract was required.

## USE OF THE LX GBS

One of the results of the LX PODAC Working Group effort is an internal NAVSEA document reporting on the results of the study and describing the methods used in developing the LX Generic Build Strategy. This document, after being updated during the Contract Design period as a result of evaluation by the shipbuilders, will serve as guidance to future NAVSEA ship design efforts in development of a GBS for their programs. However, there were direct benefits to the LX Design Team as well.

LX NOTIONAL BLOCK ERECTION SEQUENCE CHART														
<div style="display: flex; justify-content: space-around; align-items: flex-start;"> <div style="text-align: center;"> <div style="border: 1px solid black; padding: 2px;">3400</div> <div style="display: flex; justify-content: space-around;"> <div style="border: 1px solid black; padding: 2px;">3593</div> <div style="border: 1px solid black; padding: 2px;">3493</div> <div style="border: 1px solid black; padding: 2px;">3393</div> </div> </div> <div style="text-align: center;"> <div style="border: 1px solid black; padding: 2px;">6300</div> <div style="display: flex; justify-content: space-around;"> <div style="border: 1px solid black; padding: 2px;">6303</div> <div style="border: 1px solid black; padding: 2px;">6203</div> <div style="border: 1px solid black; padding: 2px;">6100</div> </div> <div style="display: flex; justify-content: space-around;"> <div style="border: 1px solid black; padding: 2px;">3193</div> <div style="border: 1px solid black; padding: 2px;">2393</div> <div style="border: 1px solid black; padding: 2px;">2393</div> </div> </div> <div style="text-align: center;"> <div style="border: 1px solid black; padding: 2px;">6100</div> <div style="border: 1px solid black; padding: 2px;">6103</div> </div> </div>														
4463	4363	4263	4163	3573	3473	3373	3273	3173	2373	2273	2171	1251	1160	
4443	4343	4243	4143	3553	3453	3353	3253	3153	2343	2241	2141	1251	1150	
4421	4321	4221	4123	3523	3433	3333	3233	3133	2311	2221	2121	1120		
4400	4300	4200	4100	3500	3400	3300	3200	3100	2300	2200	2100	1200	1100	
						3301								
						3302								
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					3402		3202							
				3501				3101						
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						3333			2301					
						3334			2302					
					3433		3233			2201				
					3434		3234			2202				
				3523				3133						
				3524				3134						
			4123			3321			2311					
			4124			3322			2312					
					3421		3221			2221				
					3422		3222			2222				
				3521				3121			2121			
				3522				3122			2122			
			4121			3353						1120		
			4122			3354								
		4221			3453		3253							
		4222			3454		3254							
	4321			3553				3153						
	4322			3554				3154						
4421			4143			3331			2343					
4423			4144			3332			2344					
		4243			3431		3231		2321					
		4244			3432		3232		2322					
	4343			3531				3131		2221				
	4344			3532				3132		2222				
4443				3530		3351			2341					
4444						3352			2342					
					3473		3273			2241				
					3474		3274			2242				

7-11

General Arrangements - Several changes were made to the General Arrangement of the LX in response to the location of block breaks.

. Transverse passageways were moved to the after side of transverse bulkheads, to thus minimize the number of longitudinal bulkheads that would exist in the way of a block erection joint.

- ☆❖❑ locks, escape trunks, etc. were relocated to the forward side of transverse bulkheads, to remove these complex structures from being directly in the way of erection breaks. This also allows them to be completed during the block construction period rather than having to be constructed on board after the block erection, thereby saving both time and labor-hours in addition to improving quality.

Structures - Numerous recommendations were made to the structural design as a result of considering the location of block breaks and erection joints.

- Stiffener Location - Stiffeners on transverse bulkheads were placed on the forward side of the bulkheads to achieve compatibility with anticipated block breaks aft of the bulkheads. Later, as the Preliminary Design structural details became available, the block break at Frame 32.5 was shifted to a location forward of the frame. This was necessary in order to allow the stiffeners to be located on the after side of the bulkhead in line with the stiffeners in the superstructure, the forward bulkhead of which is located at Frame 32.5, as can be seen in Figure 1. This led to a decision to locate the erection joint at Frame 17.5 to the forward side of the bulkhead, also, in order to have that bulkhead part of each block in Subzone 1200.

. Bilge Radius Joint- In the original mid-ship section drawing, the longitudinal butt weld for the crack arrestor strake at the bilge radius joint was located outboard of the longitudinal bulkhead that is in line with the wing-wall throughout the length of the ship. Since

the erection joint for all of the blocks along the wingwall will be inboard of the longitudinal bulkhead the weld location was changed to align with the block break, thus eliminating an extra weld along virtually the entire length of the ship on both sides of the ship.

## DESIGN FOR PRODUCIBILITY

Even before the PODAC Working Group was created, the LX Design Team had established Producibility as a major design goal and, as stated earlier, had assigned a Producibility Task Manager. His responsibility included review of all elements of the design, to identify areas where design changes could reduce cost without changing the functionality of the design - functionality being understood to include maintainability and reliability as well as operational functionality. Some of the design changes that were made while not apart of the GBS effort per se, were done keeping the ship construction process in mind.

### Hull Form Simplification Efforts

The hull form used at the beginning of PD was a conventional hull that had been developed based upon the LSD 41 class and on hull form energy efficiency work done during the AE-36 preliminary design. The intention was to develop a producible hull form based on this design. The hull form design team with input from the PODAC Working Group and from past hull form producibility efforts, proceeded to eliminate or simplify the curvatures in the hull. The areas of the shell above the waterline received the primary attention, but some changes were made to the underwater structure as well. The following changes were introduced:

**Straight Frames.** Curvature was eliminated to the maximum extent in frames forward of Frame 95. Only a few sections at the very forward portion of the bow are curved above the waterline. Similarly, a significant effort was made to obtain straight frame sections forward of Frame 95 in the region above the 9 meter waterline.

**Bulbous Bow.** The LX hull form features a bulbous bow which, though optimized hydrodynamically, incorporates some characteristics believed to be beneficial from a producibility standpoint. A knuckle is formed at the bulb-to-hull intersection in order to avoid the tight and complex curvatures associated with a fillet. Furthermore, the bulb contains sections which are, for the most part constant born Frames O-5.

**Sheer and Camber.** The decks have no sheer aft of Frame 25, where the forward section of superstructure intersects the 01 Level. Forward of Frame 25, the sheer is a straight line in the profile view. With the sheer providing ample allowance for water to flow off the deck, there is no need for camber. Thus there is no camber on any of the decks.

**Flat of Bottom.** The LX hull form incorporates a well defined flat of bottom region extending approximately from Frame 10 to Frame 125. Aft of this, a cylindrical (and therefore developable) "bottom plate" forms the transition into the flat half-siding.

**Parallel Midbody.** Parallel midbody has been provided in the amidships area, between Frames 95 and 110. Although this is only a single watertight subdivision, the parallel section extends beyond each of the two transverse bulkheads involved to allow for simple construction.

**Skeg.** The centerline skeg on the LX hull form consists of single curvature plate. It abuts the hull, forming a knuckle at the skeg/hull intersection.

**Parallel Hull Shape.** The shape of the LX hull above the third deck is identical in cross section from Frame 95 aft i.e., for more than half the length of the ship. Moreover, that shape is composed of all fiat plate sections, with a horizontal knuckle that is located above the second deck, at the anticipated location of a block break. Similarly the shape of the side shell between the 1st Platform and the Third Deck consists of flat panels of identical cross section for about 1/3 of the length of the ship.

**Ruled Surfaces.** Ruled surfaces were used in the region aft of Frame 110 below the main knuckle and above the design waterline.

**Deck Edge.** In profile, the LX hull form features a horizontal deck sheerline from the transom to Frame 25 at which point there is a knuckle in the deck sheerline and then straight sheer to the stem. In plan, the deck edge is straight and parallel to the centerline from Frame 47.5 to the stem. From Frame 47.5 forward to Frame 25, it is straight, then fairs into the stem in a convex curve.

**Flat Plate.** The entire region above the main knuckle consists of flat plate as does the raked transom.

**Crack Arrestor.** Consideration of the location of the crack arrestor joint raised the question of whether crack arrestors are needed on modern ships given the fact that the composition of steels used for ship construction has been changed greatly since the W.W. II era. As a result of this question, a study has been initiated to evaluate the requirements for crack arrestors in modern warships. If the need for crack arrestors is validated, the study will begin to look for more production friendly materials that might be used for this function in the future.

The improvements described above were made with the expectation that production man-hours for hull construction will be significantly reduced and that there will be addi-

ional labor and material savings through the decreased extent and complexity of jigs and fixtures required for forming and joining the hull and superstructure. An estimate of the anticipated cost savings was made, using the techniques described in References 3 and 4. A reduction of 10-15% of the man-hours used to construct the shell plating of the hull was predicted.

## System Simplification

One major simplification effort made during the Preliminary Design stage was to use zonal distribution systems for the electric power and lighting systems.

In warships design, electrical equipment is designated as either vital or non-vital. Vital equipment must be capable of being powered from one of two independent sources or switchboards. Non-vital equipment need only be powered from one source.

In the initial phases of PD, there were two main switchboards, one located in the forward part of the ship and the other located aft. The distribution systems for non-vital systems were run from the equipment to only one of those main switchboards. Vital system equipment was connected to both switchboards. This approach has been designated a radial distribution system because all distribution runs radiate out from the main switchboards.

The zonal approach uses two main distribution buses running the entire length of the ship, both of which are connected directly to the main switchboards through load centers located in the buses. The ship is segregated into several zones, in each of which there is one load center in each bus. All equipment located in a zone is connected to one (non-vital systems) or both (vital systems) of the load

centers in the zone. The net result is significantly less length of electric cabling, simpler and shorter wireways, and many fewer penetrations of decks and structural members.

The studies have shown that the zonal approach results in a significant material and consequently, a weight savings. However, the labor reduction is not proportional to the weight reduction since there is no change in the number of equipment hookups that must be made. That effort represents a major portion of the total electrical system installation cost.

## Standardization

The LX design accommodates several standardization philosophies, including those that have been developed by the Affordability Through Commonality (ATC) team at NAVSEA. These include the following:

- . Modular Sanitary Spaces. A separate effort has been undertaken by the ATC team to develop standardized, pre-outfitted, modular crew, CPO/NCO or officer sanitary space which will replace traditional sanitary spaces at designated locations within the LX.

- . Hatches, Scuttles, and Doors. Major openings will be of standard size and closures of standardized construction. Location of major openings also consider facilitation of equipment removal and installation.

- Standardized Space Arrangements. Replication of space arrangements was pursued within similar spaces such as the AFFF, CONFLAG, troop living, crew living, and fan rooms. Wherever possible, these spaces are identical in configuration, rather than the more traditional practice of having spaces on opposite sides of the ship be mirror images of one another. In addition to the reduction in



design and construction man-hours, this provides for standard operating procedures for each such compartment

. Stiffener Standardization. LX structural engineers made an analysis of the number of different stiffener sizes that were originally proposed in the structural drawings. They then reduced the number of different sizes by about 1/2, while remaining within the design constraints. Also, simpler stiffener shapes were used as alternatives to built-up members.

### Machinery Space Arrangements

Throughout the PD phase, the PODAC Working Group reviewed and provided comments on machinery space arrangements to the cognizant Task Leader. The comments primarily related to the grouping of system components to facilitate a shipyard's ease in assembling machinery package units for installation as a unit on block or on board. Rearrangements were recommended for the purpose of locating equipment close to other related equipment, thus minimizing piping runs and conserving space.

## CONTRACT DESIGN EFFORTS

### Shipbuilder Involvement

During the Contract Design Phase, which began in FY '94, five shipbuilders were selected to participate by sending full time representatives to be collocated at the design site with the Navy Design Team. These representatives participated in weekly staff meetings of the design team and the separate weekly meetings of the Hull, Machinery and System Engineers

with their several Task Leaders. The shipyards have been funded to carry out about twenty different studies during the CD period to date. They participated in reading sessions and provided comments on the each draft of the Ship Specifications.

## CONCLUSIONS AND RECOMMENDATIONS

The efforts of the Working Group were very well accepted by the members of the design team. The design of the LX at the end of the Preliminary Design period was a much more producible ship than it would have been without the establishment of the PODAC Working Group and the acceptance of their presence during the design period. All of the Task Leaders were very responsive to the recommendations of the Group and frequently initiated contact in order to obtain an opinion concerning the relative producibility of design alternatives that were being considered.

There was sincere interest by the design team in assuring the affordability of the design and numerous producibility improvements were generated by design team members independently of the Group. Credit for this must be given to the NAVSEA Ship Design Management from the top level to the LX Ship Design Manager, all of whom gave serious emphasis to this aspect of the design effort.

It is strongly recommended that a Producibility Task Manager be assigned in every NAVSEA design project. However, this assignment should not wait until the PD phase. On the LX project, the spacing of the transverse bulkheads was determined during the Feasibility Design phase and was essentially a given at the inception of PD. There had been no consideration to producibility aspects, such as the available steel plate lengths, when es-

establishing the bulkhead spacing. This aspect of the design might have been overridden by other design requirements, but it would not have been overlooked if a Producibility Task Manager had been assigned during the feasibility study.

while the products required of this effort could have been comfortably accomplished with the traditional pen and paper approach, the PODAC Working Group decided to use the digital data being developed by the individual design disciplines to the greatest extent practicable. This was intended to keep the products of the Working Group effectively tied to the evolving ship design and minimize the data or drawing maintenance requirements that would have been necessary to keep up with those changes. It was also felt that this might allow some additional future capability to analyze the products. This was only partially realized. Therefore, it is concluded that the CAD system that is to be used for the development of early stage ship design products must include provisions for the production planning functions necessary to develop and implement a GBS. This will ensure that production specific information that is placed in that database is available to all designers, and that production constraints may be imposed on the designers where necessary.

The GBS Study conducted during the LX Preliminary Design only addressed a few aspects of the Hull, Mechanical and Electrical (HM&E) systems design and production. In addition, to be complete, the study should have included Combat Systems design and production and total ship integration. Therefore, it is recommended that the continued studies of the GBS concept be expanded to include all HM&E systems as well as combat systems and the integration of these systems and equipment.

## ACKNOWLEDGMENTS

The authors wish to acknowledge the interest and support of NAVSEA design management, the NAVSEA ATC Team and the entire LX (LPD-17) design team. Without their commitment to making the changes necessary for designs developed by NAVSEA to be more efficiently used by shipyards employing modern shipbuilding technology and processes, the PODAC Working Group would never have been formed, and the ideas and information provided by the Group might never have been implemented. The close cooperation between the LX design team and the ATC team was an important aspect, which ensured that the design made use of NAVSEA'S best producibility thinking. Special thanks to members of the PODAC Working Group- Messrs. Len Thorell, Jack Klohoker and Larry Mossman and to Mr. Jeff Hough (ATC Team Leader) for his ideas on this paper.

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## Development of Integrated Shipyard Pipe Production Facility

Emlyn L. Jones (M), Jesse Engineering Co., U.S.A., and Terry Watne (V), Advanced Control Technology, U.S.A.

Jesse Engineering Company of Tacoma, Washington is the parent company of the Wallace Coast Machinery Company, which has designed and built pipe bending machines for many years. Working on a pipe bending machine application led to a complete pipe production modernization project in Southern China. Engineers jointly developed the design specifications for the machinery and automated controls.

Piping runs in shipboard designs are rarely the same. Each pipe assembly that is processed in a shop is different. The shipyard had developed a sophisticated computer system that identified and technically described every pipe or ventilation spool on the ship. The pipe shop however, was essentially a manual operation. Pipes were routed manually through the shop, welding was done manually, and pipes were bent using standard pipe benders.

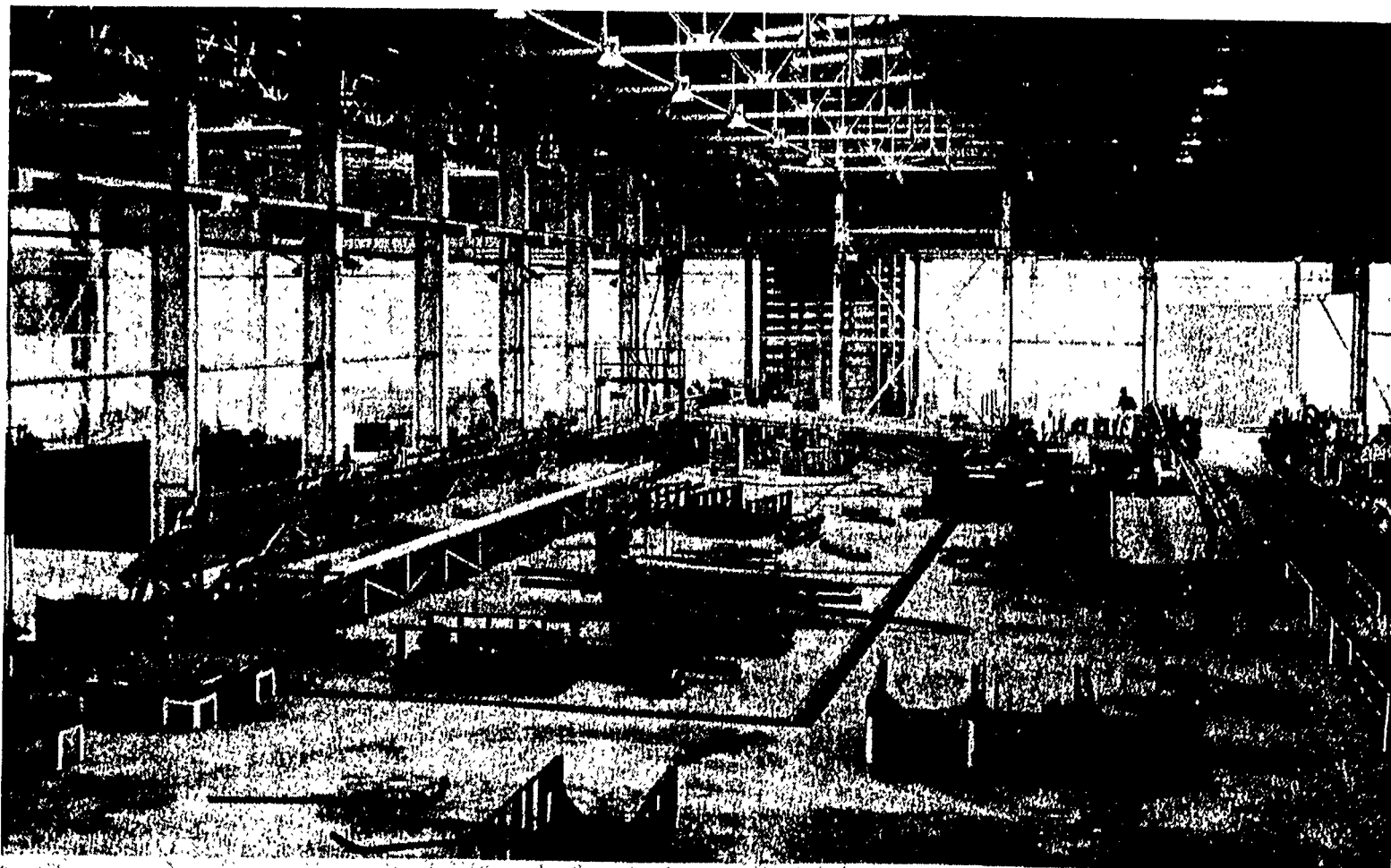
The overall engineering requirement was to automatically collect and sort the pipe processing requirements; route and track each spool through the shop; and provide automated bending, cutting, flange welding, and bending of the pipes.

### GENERAL DESCRIPTION SHIPYARD SYSTEM

The new factory layout uses three production lines. The small line handles pipes from 15 to 50mm (1/2" to 2"), the medium line from 65 to 150mm (2 1/2" to 6"), and the large line from 200 to 500mm (8" to 20"). The small and medium lines are semi automated production lines with similar equipment. All pipe transfer operations on the large line are manual and the equipment is basically manually operated.

For ease in presentation this paper only describes the medium line. Figure 1 shows the medium line as installed. Figure 2 shows the equipment layout of the medium line with arrows showing the production flow.

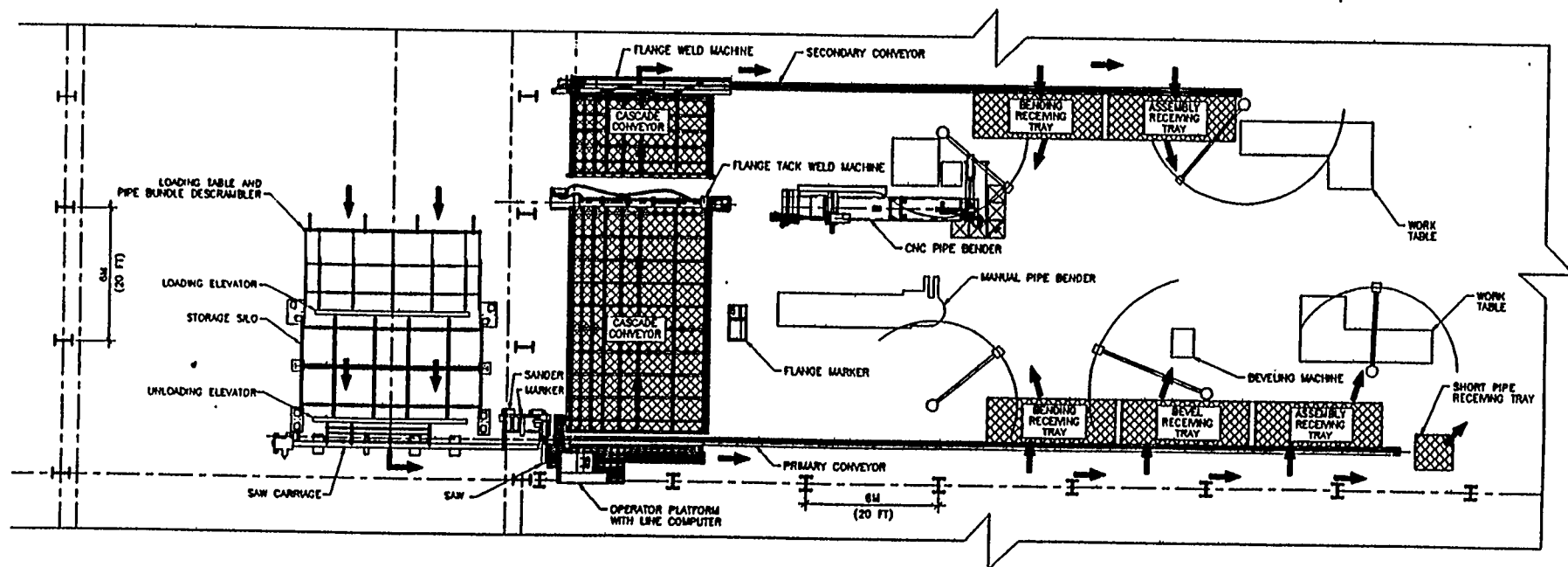
The medium line is designed to produce 41,000 cut pipe spools per year or 17 per hour. Each pipe has particular end treatments, and many have holes or saddles. Pipe assemblies are completed in the facility ready for installation aboard ship. 14 cut pipes per hour are sent to the automatic flange welding station and 6 pipe spools per hour are bent in the CNC Pipe Bender.



### **Medium Line Machinery**

Medium line machinery, showing new installation at shipyard facility.

Figure 1



LAYOUT OF MEDIUM LINE

FIGURE 2

All pipe production activity is scheduled in the office using a 486-PC computer. The cutting and bending schedules are transferred to the line control computer and the CNC pipe bender control computer on the factory floor. Production status data from these computers are sent back to the office computer. Figures 3 and 4 are simplified information flow diagrams for the medium line.

Accommodating long production runs using pipes of the same diameter, thickness, and material was a key design consideration. This provides two major advantages.

1. Equipment can be designed with manual setups for different size pipes. The time involved making these equipment changes detracts little from the overall production rate if the changes are made infrequently. This also reduces the automatic mechanisms required. The machinery is simpler and less expensive to manufacture and maintain than fully automated equipment which can make all size changes automatically.
2. The greater number of cut pipe pieces that can be nested onto the uncut pipe inventory at one time results in less pipe waste.

#### **OPERATING FEATURES**

Bundles of the same size pipe are placed on the storage silo loading table. The pipes are ordered on the loading rack by the descrambler mechanism.

They are automatically transported to the appropriate storage tray in the silo by the loading elevator.

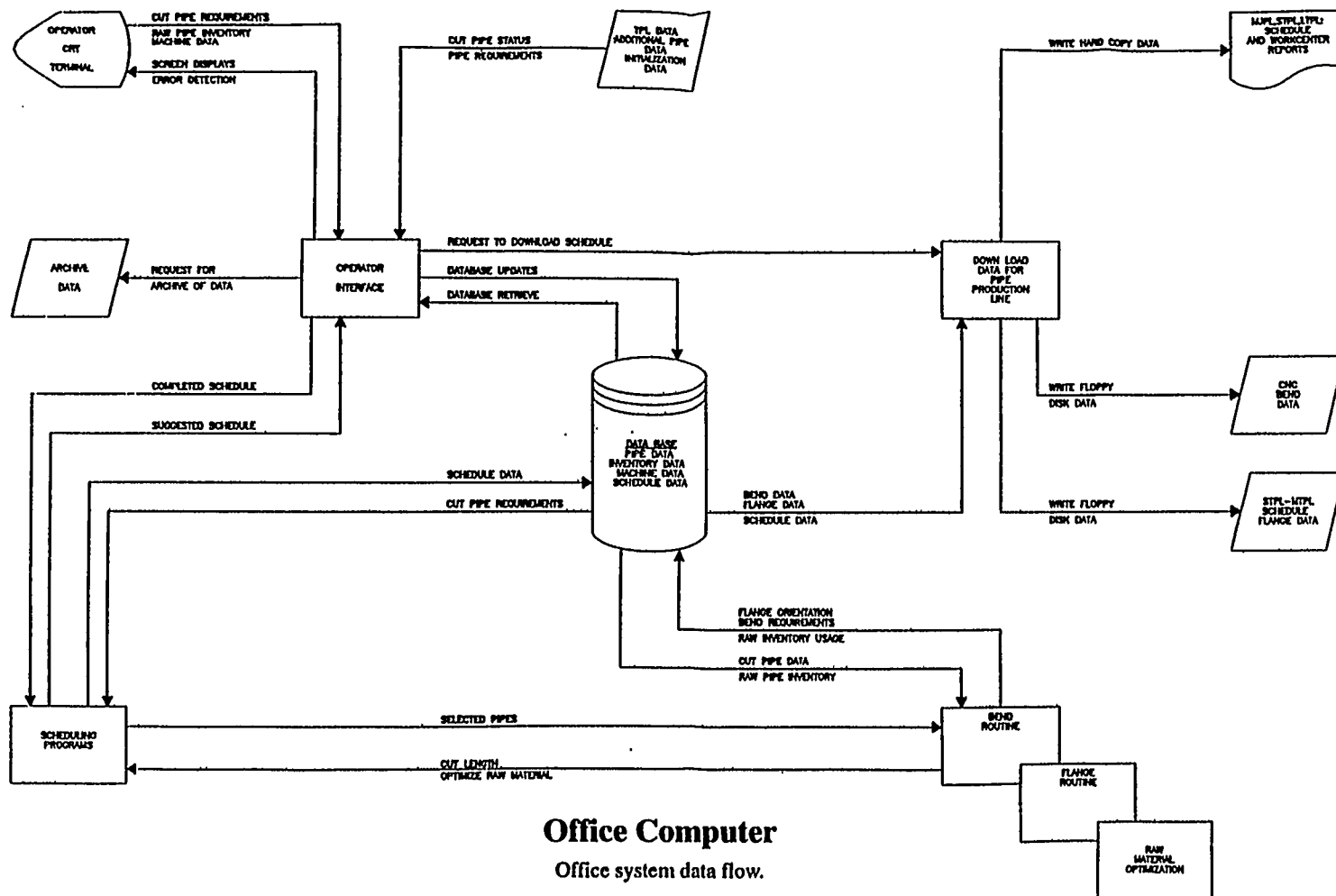
Pipes to be processed are automatically scheduled and efficiently nested onto the stored pipe inventory. The correct size pipes are automatically drawn from inventory. Each pipe piece is then automatically cleaned (sanded) for welding as required; marked by an ink jet printer; saw cut to the correct length; and conveyed to one of six stations for further processing. Pipes are automatically marked with unique pipe numbers assigned by the shipyard. Each pipe is also marked with a series of numbers indicating its work flow sequence. Flanges are automatically engraved with the associated pipe numbers at the flange marking station.

The correct flanges are aligned and mounted to the cut pipe pieces in the flange tack welding machine. They are tack welded and conveyed to the flange welding machine.

The pipe is positioned in the flange welding machine and four automatic welding guns simultaneously weld the two flanges to the pipe.

The CNC Pipe Bender stores all of the scheduled bends in its computer memory including the machine setups. The operator selects a pipe from the bender collection table, enters the pipe number marked on it, loads the pipe, and the bender performs the bends.

The work station sequence numbers show the work sequence in which a pipe piece must flow on the factory floor. End beveling, hole cutting, saddle cutting, and final assembly are typical work station areas.



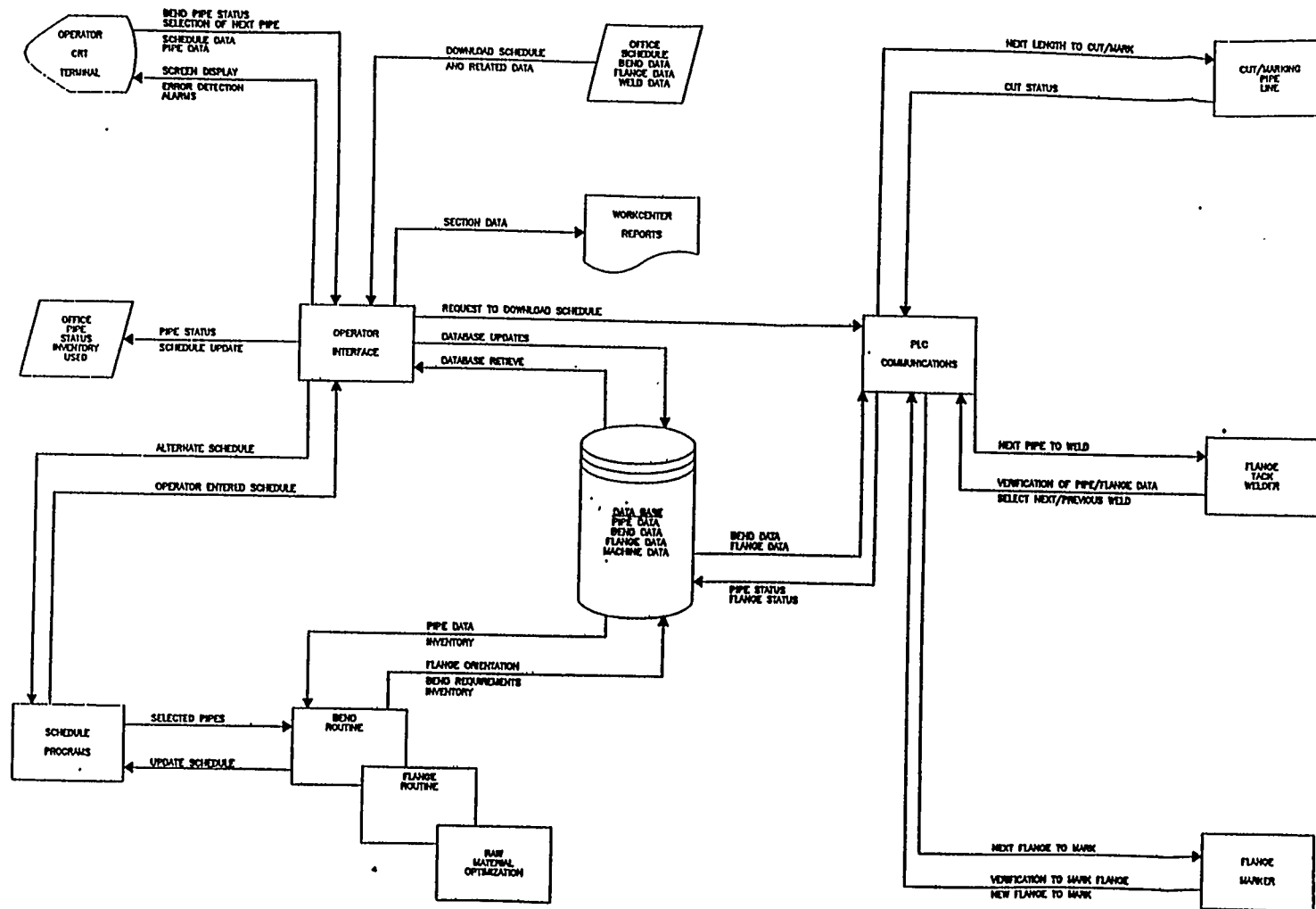
# Office Computer

Office system data flow.

Fig. 3

Figure 3

Figure 4



**Line Computer**  
Line control computer data flow.

Fig. 4



Work station operators are provided computer printouts listing the pipes which have been scheduled for their work station and pertinent information concerning each piece.

The line control computer and the CNC pipe bender control computer send pipe status back to the office computer. Automatic status information includes: pipe is cut, flange is marked, flanges are tack welded, and pipe bent. This status information is used by the office computer operators to either reschedule the pipe or move the pipe data to an archive file.

## DESIGN FEATURES

### computer System

The control program uses a commercially available database program as the basic scheduling tool. Data for each cut pipe is entered at the office PC or can be entered by means of floppy discs. The discs are developed by the shipyard's engineering and production departments. The engineering department provides the technical data for the pipe including its number, its bend definition, and its end treatments. The production department provides the routing sequence through the shop for each cut pipe and its required date.

Automatic data look-up tables keyed to pipe size, bend data, and end requirements simplify the entry requirements for each cut pipe. These look-up tables provide data required by the various machines.

The production schedule and all necessary data is passed to the line control computer and the CNC pipe bender control computer.

The schedule data is passed from the control computers to Programmable Logic Controllers (PLCS) which control the automated, sequential functions of the various machines.

### Special Programs

The pipe bending program converts the desired bend requirements into machine instructions for bends, carriage tangent moves, and carriage chuck rotations. The bend instructions produce the desired finished bent pipe. The bend instruction calculations consider pipe spring back and provide for over bending to insure the finished bends are the desired angles. The tangent lengths between bends are also adjusted to insure the final total spool length is as specified. Pipe material spring back values are used as the basis for these calculations. The spring back values are determined and entered by the operators. An important output of this program is the cut-length of each pipe. It is an adjusted length that insures the flange to flange length of the finished pipe spool is correct after it is bent.

The cutting optimization program is an adaptation of a proprietary program used to order and cut steel shapes. The program uses an iteration process to fit cut pieces onto the inventory in a manner that minimizes pipe waste.

A special flange orientation program was developed to calculate: (1) The required offset angle between flanges on a cut pipe such that holes continue to be aligned after the pipe is bent; and (2) the initial pipe rotation required at

in the bender to cause the flange holes at each end of the pipe to line up correctly aboard the ship. The flange orientation aboard the ship is set by rules provided by the shipyard. The input bend data for each pipe spool includes its X Y Z projection lengths on a shipboard coordinate system. The data also indicates flange orientation of 2 holes up or 1 hole up. The shipyard already characterized all of their pipe bending coordinates in a shipboard coordinate system. Knowing the shipboard orientation of the bent pipes is a necessary requirement for this type of program.

The data base program presents a suggested list of cut pipes to the office computer operator sorted by pipe size and prioritized by required date. The operator approves or changes the list. The selected pipes are automatically nested and scheduled for cutting. The operators have the ability to change this schedule at the office computer or at the line computers.

#### Line Computer Communications

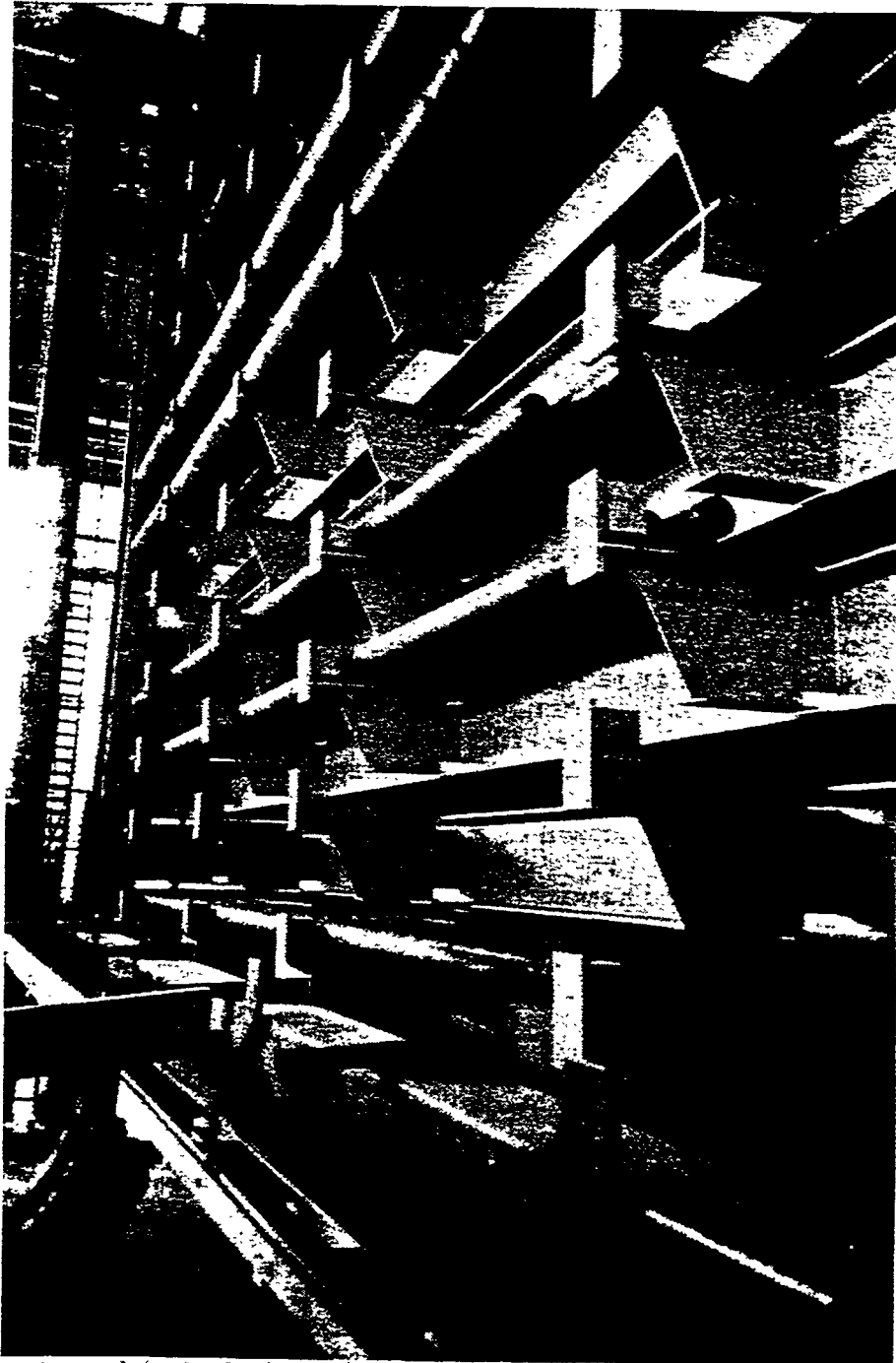
The line computer is an industrialized 386 PC and communicates with the PLC using a Data Highway network. This provides the means for the line computer to send and receive data for processing the pipe. The PLC can alert the operator through the line computer of any equipment failures or error conditions that may occur while the pipe is being processed.

After a pipe is selected for processing by the operator the line computer sends the rack location to retrieve the pipe, length of the pipe, where each operation on the pipe is to be performed (sand, mark, cut), and the location where the pipe is to be kicked off the conveyor. The PLC sends status to the line computer as the PLC retrieves the pipe from the rack location and processes the pipe. In turn the line computer updates the data in the local database to reflect the status of the raw material inventory and the current status of the cut pipes.

The line computer also provides communications to the ink jet marker. When the PLC has positioned a pipe to be marked, it sends a signal to the line computer to initiate the marking of the pipe. The line computer sends the required commands to the ink jet marker to perform the mark. When the mark is completed, the line computer signals the PLC to continue processing. A similar system is used at the Flange Marking and Flange Tack Welding machines. These machines have a key pad and small display. The operator signals the line computer when to start a selected process. The line computer then sends the proper commands to the PLC.

#### Storage System

The Medium Line storage silo (See Figure 5) stores more than 600 pipes. 15 different sizes between 5M (16ft.) and 8M (28ft) long are stored in 15 sloped storage trays. It is a steel silo approximately 8M (26ft) high, 9.5M (31ft) wide and 6M (20ft) deep.



### **Storage Silo**

*Shows unloading elevator and pipes in the trays.*

Figure 5

The pipes are deposited in the trays by the loading elevator and roll to a stop at the other end. Bundles of the same size pipe are loaded on the feed table. The loading elevator individually transports the pipes to their designated trays. The unloading elevator is sent to the appropriate slot by the line control computer where it automatically strips a single pipe from the tray and deposits it in the saw line carriage. The elevators are similar in design and are driven by electric motors. Various pneumatic arms on the elevators accomplish the pipe transfers. There are no actuators located on the silo.

#### Saw System

The saw carriage (See Figure 6) consists of a series of grippers, some configured for rotation and others for longitudinal transporting of the pipe. The grippers are designed to self-center pipes of any diameter. Three transporting grippers pick the selected pipe from the unloading elevator and swing the pipe to the carriage center line axis. A pneumatic, rotatable chuck moves forward and grips the pipe. The chuck positions the pipe for all operations. A position seeking AC motor drives the carriage and pipe to precise linear locations within a tolerance of  $\pm 1$  mm. Each pipe piece is first cleaned by a 6" belt sander in the areas to be welded, and then marked by an automatic ink jet marker before it is cut.

The pipe is cut while it is rotating using a band saw. This insures a straight cut and also eliminates any saw burrs on the outside of the pipe.

The pipe breaks a sensing light beam as it is moved forward by the chuck. This sensor sets all pipe measurements. The computer calculates sequential stops as it moves forward to be sanded, marked, or cut. The longitudinal or radial grippers are air operated and grip or relax depending on the pipe motion. The grippers swing completely out of the way to allow the chuck to pass. There is a radial gripper on the out-feed side of the saw. The saw outfeed conveyor also automatically adjusts its height to the bottom edge of the pipe being sawed. The conveyor is fitted with an adjustable fence that holds the pipe in line as it rotates under the saw. The saw line conveyor is a chain conveyor that automatically transports the cut pipe pieces to one of five kick-off locations. Air operated kick-off arms automatically sweep the pipe to holding tables or other conveyors. The work flow sequence number assigned to the pipe piece determines the kick-off it is sent to.

#### Tack Weld Station

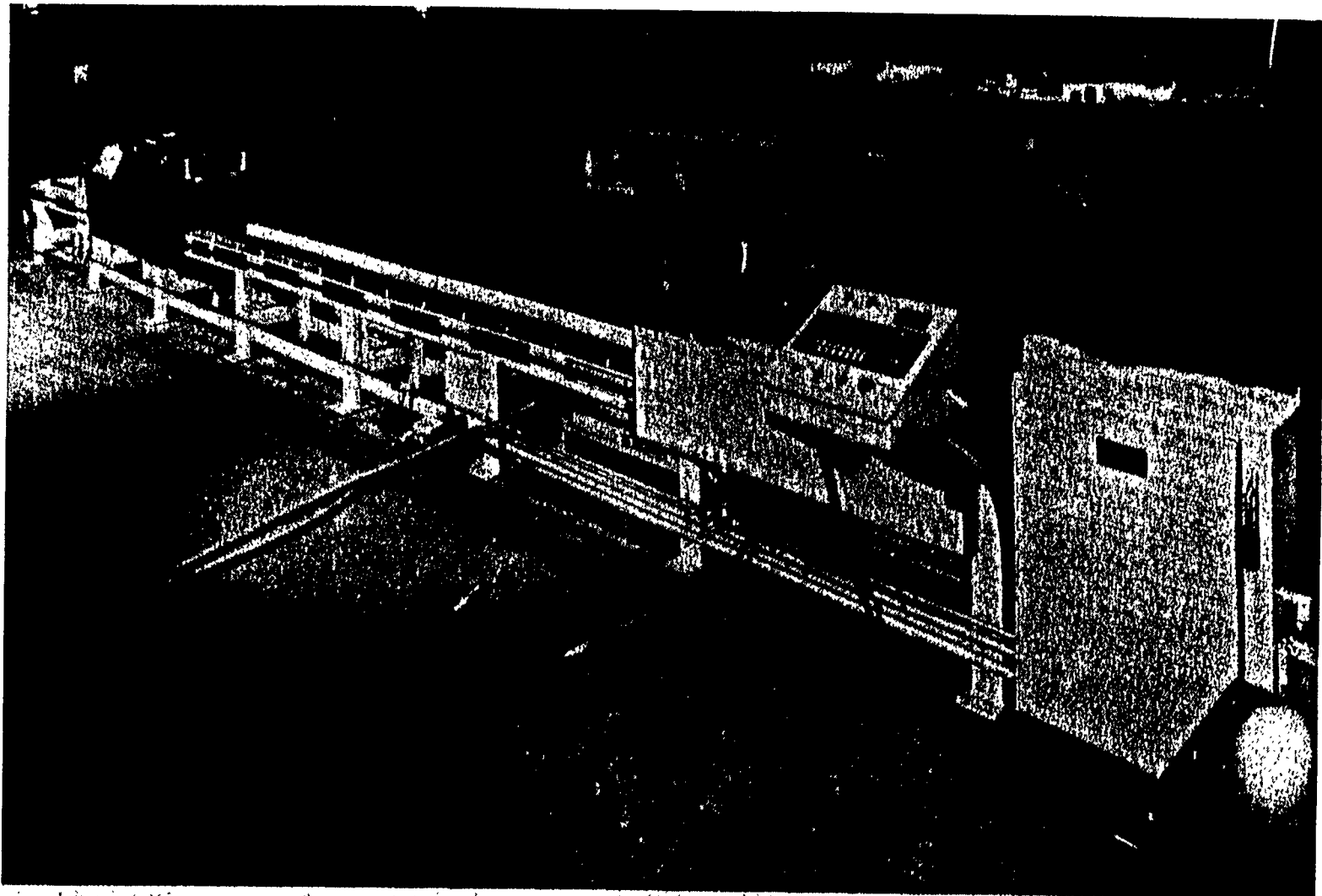
Pipes that are to be flanged are sent to kick-off #1. They roll down a computer controlled, pneumatically operated, cascade conveyor. The conveyor can store up to 10 cut pipes and delivers them individually to the tack weld machine. The tack weld machine has two scrolling type chucks operated by air motors (See Figure 7 & 8).

Figure 6



### Saw Line

Shows pipe being processed, #1 kickoff, cascade conveyor, manual control panel, band saw, outfeed gripper, saw carriage, large self-centering grippers holding pipe, chuck holding pipe, unloading elevator, and storage silo.

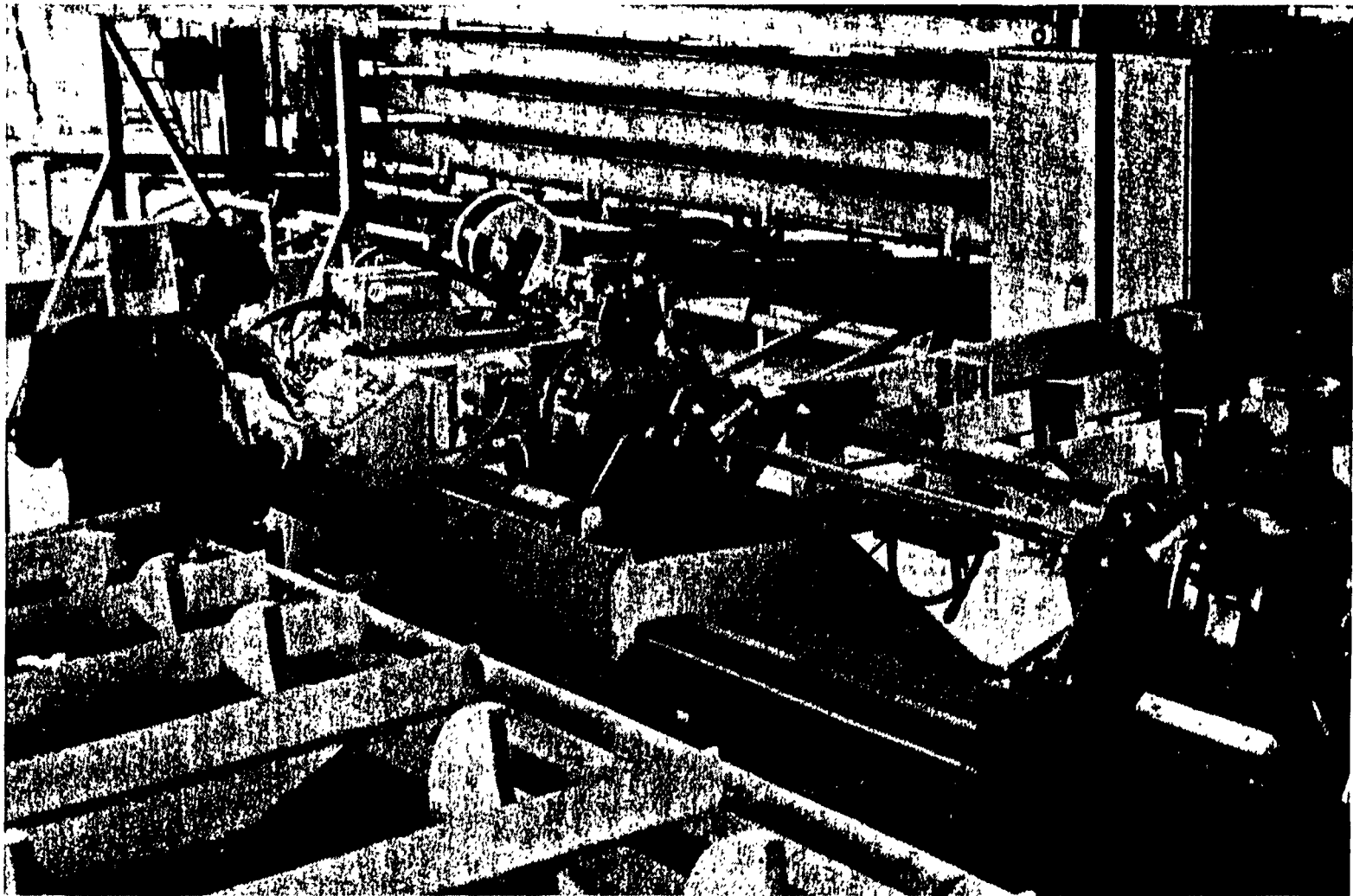


### **Tack Welding Machine**

Shows self centering grippers, chucks, control panel, and remote I/O cabinet for data communications with the line computer.

Figure 7

Figure 8



### Flange Tack Weld Machine

Shows pipe centered in the gripper, flanges in the chucks pushed on to the pipe, cascade conveyors on the loading and unloading side of the machine.

The chucks are mounted on air actuated slides which move toward or away from the positioned pipe. There is a fixed and a movable carriage assembly. An AC electric motor automatically positions the movable carriage. The home position of the movable carriage is close to the fixed carriage. A digital display shows the operator the number of the next pipe as well as the setup information required. The operator places a pipe spacing ring and an indexing pin on each chuck face. This setup is the same for each size of pipe. The operator places the flanges in the chucks with the indexing pins through one of the flange holes. The flanges are held flush against the chuck by magnets imbedded in the faces. The operator uses a push button to close the chuck jaws. The operator manually sets the required flange hole offset angle using a digital readout. The system was designed to set the flange offset angle with .1 degree. The movable carriage automatically positions itself to accept the pipe piece waiting in the cascade conveyor. Grippers, similar to those used on the saw line carriage, pick the pipe from the cascade conveyor and center it between the chucks. The chucks are automatically pushed forward by the air cylinders positioning the flanges on the pipe. The operator manually tack welds the flanges to the pipe.

When the tack welding is completed the chuck jaws automatically open, the chucks are retracted, and discharge arms automatically move the pipe to another cascade conveyor. The movable carriage positions itself for loading the next flange.

## Flange Welding Station

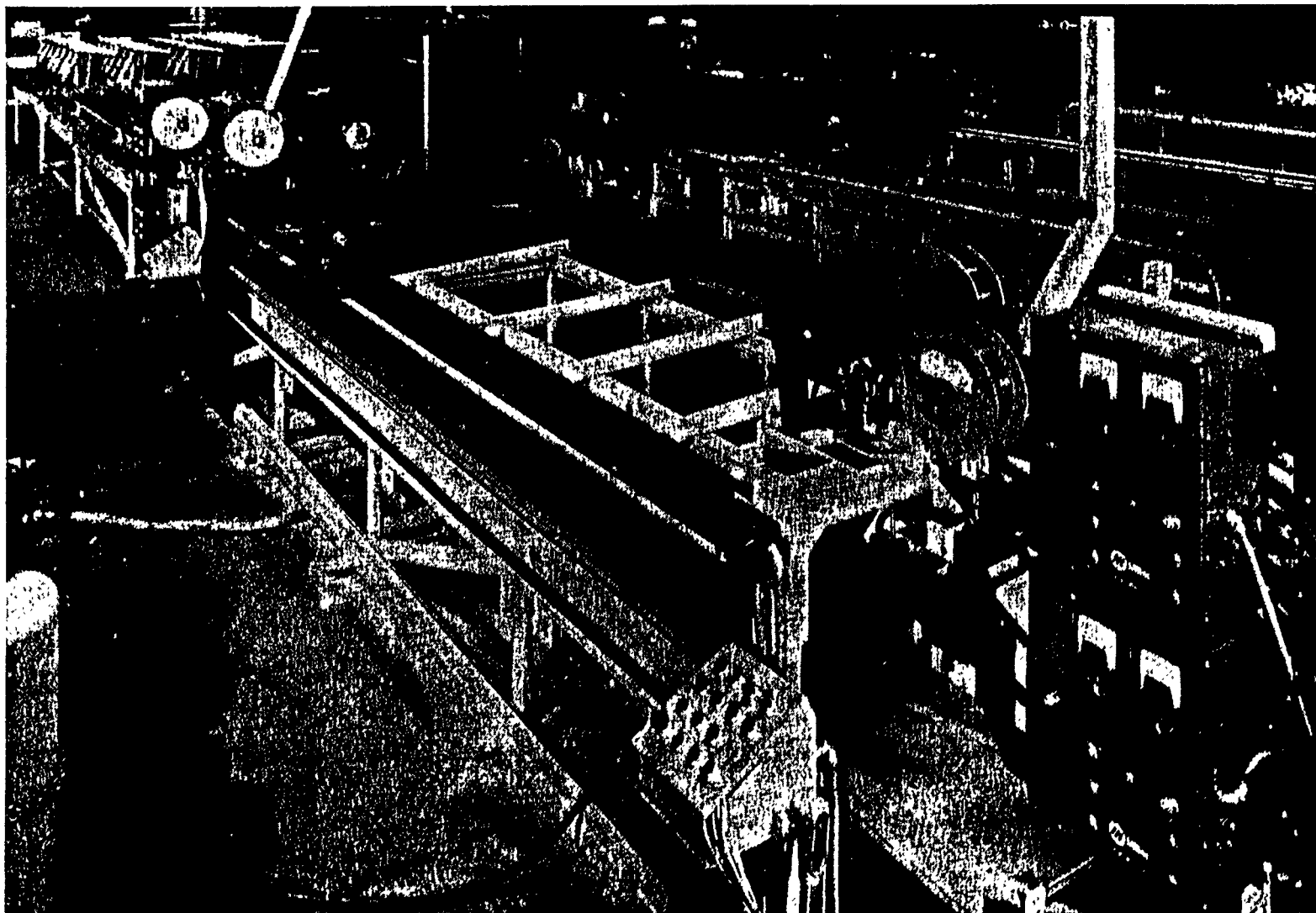
The flange welding machine (See Figure 9) uses 4 commercially available, automatic welding machines. There is one fixed and one movable carriage with two guns mounted on each carriage. The guns are on air operated arms which swing the guns into or away from the work area. The guns are manually adjusted for a particular pipe/flange configuration and will hold that adjustment as they are swung in and out of the work area. Guide rollers ride the work pieces and keep the guns in position while the pipe turns.

The operator aligns the movable carriage with the incoming pipe. The pipe automatically rolls onto the carriages and rests on 4 turning rolls. The pipe is automatically positioned and the four weld heads swing down. The operator insures the heads are positioned correctly then starts the welding process. The pipe rotates under the weld heads. When the weld is completed the operator turns off the welding machines. The operator makes all weld settings and can manually operate any or all the heads as required. The roller arms automatically lower the welded pipe to the secondary conveyor at the completion of welding for transport to one of two kick-offs.

## Flange Marking Machine

Pipe numbers are permanently engraved on the flanges using a commercially available automatic marking machine (See Figure 10).



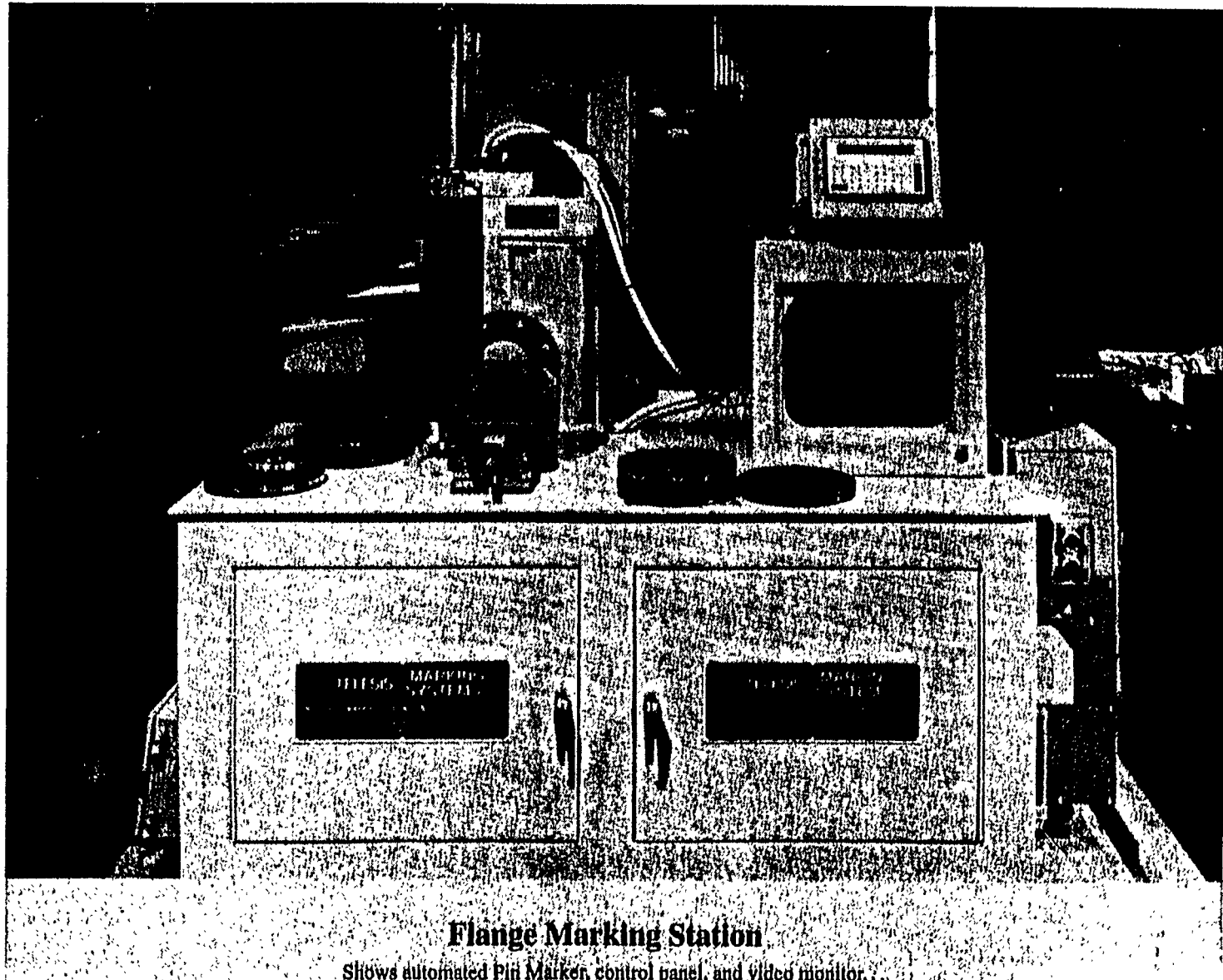


### **Flange Welding**

Shows pipe set for welding, 4 welding machines, secondary conveyor integral with welding machine, and control consoles.

Figure 9

Figure 10



### Flange Marking Station

Shows automated Pini Marker, control panel, and video monitor.

The machine consists of a computer control module, an automatic positioning arm, an automatic rotating chuck, and an air operated pin stylus that makes a mark in the metal. The flanges are mounted on the rotating chuck. The arm automatically swings over the center of the flange edge, the stylus is turned on, and the proper characters are engraved into the flange.

The starting position of the arm and the character size are preprogrammed into the machine. The line computer sends the marking machine the character string to be stamped and the pattern name to be used.

A digital display prompts the operator with the next scheduled flange number, its specification data, and its destination. The operator mounts an appropriate flange on the chuck and pushes a button. The flange is automatically marked.

### CNC Bending Machine

The medium line uses a 1006 CNC Pipe Bending Machine (See Figure 11). The basic machine comes with the ability to load and store bend requirements by number for later recall. The machine has automatic spring back compensation and automatic radial growth compensation as a standard feature. This application required bending pipes already cut to length and flanges welded on both ends. The following changes were made to the standard machine.

1. Provided a scrolling hydraulic chuck which could grip flanges as well as pipes. The chuck has an indexing slot in the face that accepts an indexing pin inserted through a flange hole.

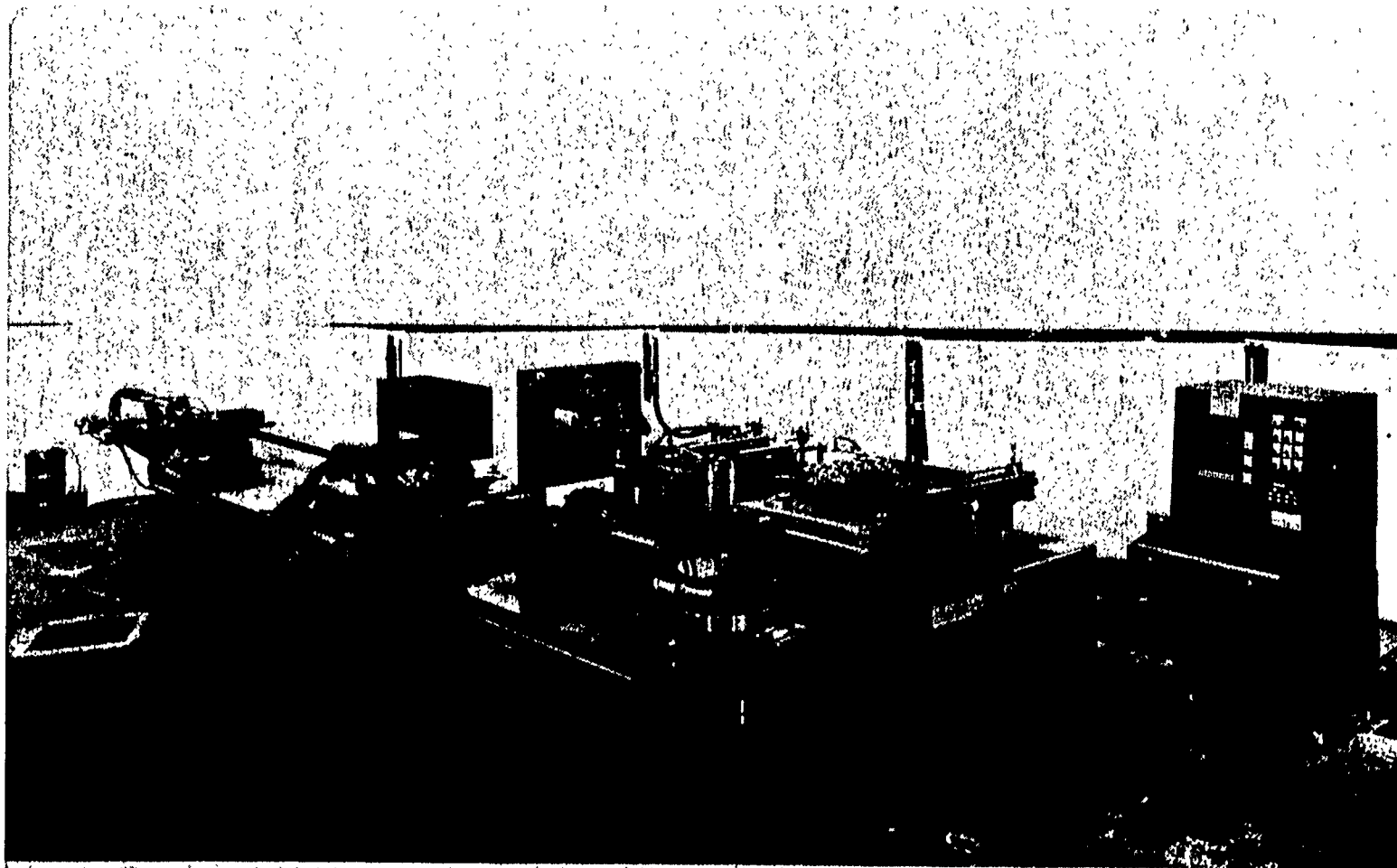
This provides for manual indexing of the flange. The flange hole is indexed within .1 degree.

2. Provided a laser hole finding device. This device drops in front of the flange after the pipe is loaded. The pipe is automatically rotated and the laser device signals the bender computer when it detects the edges of a hole. This provides for automatic indexing of the flange.
3. Provided a computer interface that accepts the pre-calculated and prescheduled bending information from the office computer.

The operator selects a pipe from the collection station and reads its pipe number. The number is located on the bender computer screen. The screen automatically displays the bender information required for that pipe. The operator insures the bender is setup properly and loads the pipe. The bender automatically makes the proper 3 dimensional bends.

### ADDITIONAL FEATURE

A system has been developed that incorporates an automatic pipe measurement device as part of the storage silo loading elevator. The length of each pipe is measured as it is loaded on to the elevator and the value automatically recorded by the line control computer. The cutting program considers the length and location of each pipe in the rack as it calculates the optimum nesting arrangement.



### **CNC Pipe Bender**

Shows CNC pipe bender, control console with the control computer, modified chuck and laser hole finder under its hood.

Figure 11

## CONCLUSION

The equipment described in this paper was designed, manufactured, and delivered to the shipyard within 9 months of the contract date. Combining state of the art automation with manual operations produced an efficient system using simple and reliable machines. The productivity rate of the working line is high. Overall shipyard efficiency is increased by automatically linking the pipe shop scheduling data, the shipyard production data, and the engineering requirements data.



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# Standard Outfit Package Units in the LPD 17 Ship Design: A Production Impact Study

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## ABSTRACT

Standard outfit package units for reverse osmosis plants, fire pumps, steering gear, and sanitary spaces were proposed for the LPD 17 amphibious transport dock ship design. The ship was in the preliminary design stage, and it was necessary to determine how this shift to outfit modularity would affect the ship procurement program. Because the use of package units would not have a significant impact on the overall characteristics and performance of the ship, the focus of the investigation was on material ordering and production scheduling. The analysis took account of zone-area-stage outfitting methods and also more traditional practices. With either approach, it was found that the package units did not present any schedule or procurement problems. This particular study was focused on a very specific issue, but the approach is applicable to a wide range of production impact assessment problems.

## INTRODUCTION

A new series of standard shipbuilding outfit package units for naval construction is being developed by the Navy's Affordability Through Commonality Program (ATC). These package units are also variously known as common modules, standard outfit modules, or other similar names; the nomenclature has not yet been standardized. This production impact study was undertaken in order to help integrate four types of package units into the design of the LPD 17 class amphibious ship. The four units studied were ATC's reverse osmosis, sanitary space, fire pump, and steering gear outfit package unit designs.

The goal of this study was to identify production process implications of using the four ATC package units in the LPD 17 design, and in particular to determine construction schedule impacts. This was accomplished by integrating the modules into a notional construction strategy that was under development for the LPD 17. The general outline of the analysis was as follows.

a) The LSD 49, whose principal characteristics are compared to those of the LPD 17 in Table I, was identified as the most similar ship which had already been built. The analysis started with an existing ship because the notional LPD 17 construction strategy was not detailed enough and did not include a compartment

Characteristic	LSD 49	LPD 17
<b>General</b>		
Length (overall)	186 m (610 ft)	208 m (684 ft)
Beam (extreme)	25.6 m (84 ft)	31.9 m (105 ft)
Draft	6.1 m (20 ft)	7 m (23 ft)
Displacement (full load)	approx. 17,000 long tons	approx. 24,000 long tons
Total accommodations	approx. 400 crew approx. 400 troops	approx. 495 crew approx. 750 troops
<b>Propulsion</b>		
Main engines	4 medium speed diesels	4 medium speed diesels
Number of shafts	2	2
Shaft horsepower	33,000	40,800
<b>Operations</b>		
Operational mission	Transport and launch loaded amphibious craft and vehicles with crews and embarked personnel in an amphibious assault.  Render limited docking and repair service to small ships and craft.  Act as primary control ship in an amphibious assault.	Amphibious transport dock ship for Marine landing forces via helicopters, and amphibious assault vehicles
Flight deck capability	Two helo landing spots	Four helo landing spots
Hangar bay	None	Yes
Well deck capability	LCAC and conventional craft	LCAC and conventional craft

Table I Selected characteristics of LSD 49 and LPD 17.

closeout schedule or a block erection schedule.

b) The time frame or insertion point for fitting each ATC module into the LSD 49 baseline schedule was determined.

c) The findings were extrapolated to the LPD 17.

d) The material ordering lead times for the modules were derived.

e) The material ordering lead time was checked against the baseline schedule to ascertain whether or not a potential conflict existed.

In conducting this study, the LPD 17 construction planning information used (block breaks, scheduling information, and related information) was taken from preliminary elements of a notional build strategy which was under development by the LPD 17 design team. The notional build strategy was intended to help the ship design team to incorporate producibility considerations into the design of the ship.

#### **PRODUCTION IMPACT STUDIES: CONCEPTS AND METHODS**

During the planning of a new ship acquisition program, feasibility studies are performed to determine how various design constraints will affect ship acquisition. A baseline ship design is developed, a change is specified, and the design is modified to accommodate the change. A comparison of the modified ship design to the baseline reveals the impact of the change. Ship impacts may be broken down into impacts on principal dimensions, weight, stability, cost, combat capability, mobility, damage resistance, and so on. The results are used in evaluating proposed future ship configurations and systems, and, at a higher level, in developing ship operational requirements and in planning and prioritizing research and development projects (Sims, 1993).

Ship impact studies are an essential tool, but for certain kinds of design decisions they do not reveal all of the significant consequences. A ship impact study looks at a ship only as a finished product. However, some design changes are intended to affect the acquisition process more than the final ship. In these cases, an appropriate type of process impact study must be carried out.

Incorporating the four ATC common modules into the LPD 17 design is expected to have relatively little final ship impact (*Modularity*, 1993). Instead, the modules are intended to benefit the program by reducing shipbuilding cost and time. In other words, the completed ship will not change significantly, but there will be improvements in the way the ship is built. This production impact study was conducted to study

different design options whose major impacts will be on production processes rather than the final product.

The value of doing production impact studies at increasingly earlier stages of design is becoming clear, and some progress has been made in developing techniques and criteria for evaluating the construction cost differentials of ship design options (Wilkins, Kraine, and Thompson, 1993). This study of the LPD 17 program looked at the impacts of the proposed design change (incorporation of ATC package units) on production scheduling and material ordering. Because the LPD 17 was in the preliminary design stage, construction planning had not yet been done to a level of detail which permitted production impacts to be investigated. The LSD 49 was chosen as the baseline for this project because it was the most similar existing ship; then, the methods and findings were transferred to the LPD 17.

The basic idea behind this analysis was to find construction blocks which contained a function that could be served by an ATC module, replace the existing equipment with the module, and find the point in the ship construction schedule where the module could be fitted. This date -- when the module is attached to the next higher assembly -- is called the insertion point. Subtracting the module's material ordering lead time gives the date when the shipyard must award the purchase order to the manufacturer, or alternatively, when the yard must begin to build it at its own facility. The ATC module insertion point and purchase order award date are studied in reference to the ship construction plan to determine whether incorporating the modules will cause any disruptions in the production process or schedule.

This procedure may be summarized in eight steps.

a) Identify compartment locations on the LSD 49 where ATC common modules could replace existing systems.

b) Associate each such compartment with a construction block.

c) Lay out the construction schedule for each block containing a module, from start of fabrication to erection.

d) Select the start of on-block outfitting as the module insertion point.

e) Identify LPD 17 compartment locations for the ATC modules, and associate each such compartment with a construction-block.

f) Estimate construction schedules for the LPD 17 blocks using the LSD 49 schedules, step (c), as a guide. For each LPD 17 block, identify the start of on-block outfitting, and use this as the ATC module insertion point (similar to LSD 49, step (d) above).

g) Estimate module ordering lead times.

h) Obtain the purchase order award date by subtracting the estimated material ordering lead time from the module insertion point.

The delivery date, step (d), is the earliest and therefore most demanding from the standpoint of production planning. Actual dates will vary with differences in facilities, production processes, labor, order book, and other operational factors. The earliest delivery is required in cases involving large pre-outfitted blocks built away from the erection site. This process depends on delivery of modules during the on-block outfitting stage. Shipyards which do less extensive block pre-outfitting are able to take delivery of the modules at a later stage of construction.

### ATC STANDARD OUTFIT PACKAGE UNITS

The sanitary space module design is a pre-outfitted, box-like, non-structural enclosure equipped with toilets, urinals, sinks, showers, a service sink enclosed in its own mop and broom locker, peripheral amenities, compartment lighting and power, heating, ventilating and air conditioning services, and associated piping. It may be open at the top, bottom, or at both (*Modularity*, 1993). The design of this module is subject to change in virtually all respects including geometry and capacity. However, the material ordering lead time and insertion point will not change significantly as these design issues are resolved.

The fire pump module is built around the Navy standard 3,785 liters/min. (1,000 gal./min.) fire pump, which is designed to provide pressurized sea water for fire fighting, sanitary uses, wash down, and primary or back-up cooling service. The pump-motor assembly is resiliently mounted to a sub-base. Bolted to this sub-base is a frame assembly that supports the pump ancillaries including a motor controller, automatic bus transfer, gage board and casualty power terminal. The pump inlet and outlet will be fitted with flexible connections by the shipbuilder because their length and arrangement are best left to the detail design of ship's piping and machinery arrangement. The weight is approximately 1,700 kg (3,800 lb.) The sub-base is approximately 180 mm (7 in.) deep and the scantlings have been selected to support the equipment weight using naval surface combatant shock design criteria. This module is intended for use aboard a combatant type vessel. For ships where noise and shock criteria do not apply, the resilient mounting and flexible connections could be deleted or replaced with solid mounts and pipe, but otherwise the design and production process would be identical (*Modularity*, 1993). Offering an optional mounting would not

introduce enough variety to significantly impair the commonality of the module. In fact, the provision of application-specific mounts or foundations can in some cases advance commonality by allowing standard outfit package units to be installed in a wider range of operational environments than they would otherwise be able to serve. In these cases, effective module designs must strike a balance. The number and scope of options must not be so great as to impair commonality, but on the other hand options that greatly increase the potential applicability of the module should be evaluated for possible incorporation.

The reverse osmosis module is a 45,420 liter/day (12,000 gal./day) unit which processes sea water into fresh water. The ATC module is made up of a pump sub-module, a reverse osmosis sub-module and a filter sub-module which are resiliently mounted for structure borne noise reduction. The module also incorporates a motor controller and gage panel, which are hard mounted. The interconnecting piping incorporates the necessary instrumentation and control devices and is flexibly connected to the pump and reverse osmosis sub-modules. The piping is resiliently supported from the module sub-base. The estimated wet weight of the module is approximately 6,800 kg (15,000 lb.) The sub-base is approximately 23 cm (9 in.) deep and the scantlings are sized to support the equipment weight using naval surface combatant shock design criteria. Structure-borne noise control features are consistent with DDG 51 Class criteria (*Modularity*, 1993).

The steering gear module is made up of sub-modules including rudder actuator assemblies, hydraulic power units, a hydraulic fluid power supply system, a hydraulic fluid storage system, and an emergency fill/drain pumping system. Some recent U.S. Navy ship designs (DD 963, FFG 7, CG 47, and DDG 51 classes) already show commonality in the power units, service tank units, storage tank units, and fill/drain/emergency pumps (hand and motor driven). The rams and cylinders and type of steering gear are diverse, being determined by rudder stock position, tiller flat space and torque requirements at a 30 degree rudder position. All power units are presently in a modular form. The motors, pumps, trick wheel/differential controllers, filters, valves, and servo control valves are mounted on a skid (*Modularity*, 1993).

### SHIP CONSTRUCTION PROCESSES AND ATC PACKAGE UNITS

The overall processes of ship construction are considered in finding the right schedule point for the



insertion of the ATC modules. Ship construction work may be classified in several ways depending on what aspect of the work is of interest. Under the product work breakdown structure concept, shipbuilding work activities are grouped into three primary types: hull construction, outfitting, and painting. Hull construction and outfitting are further broken down into fabrication and assembly, which are sequential stages of production.

The notional construction strategy for the LPD 17 uses the hull block construction method and zone outfitting. Zones are geographic parts of the ship. The boundaries are laid out in the construction plan and cover functional parts of the ship; for example hull, machinery, and superstructure. For warships, zones may be added for combat systems (Storch, Hammon, and Bunch, 1988, p. 62). Within a zone, work is organized by problem area (production process attribute) and by production stage, thus giving the complete zone-area-stage product oriented work breakdown system.

For outfitting work, the object is to plan the work to take advantage of the optimal environment for the particular production process involved. There are three stages for outfit work: on-unit, on-block, and on-board. High outfitting productivity is most readily achieved when the work is performed at the earliest possible of these three stages (Chirillo, 1983). For this reason, and because it represents the most difficult constraint on planning, the earliest feasible stage was chosen for the insertion of each ATC module into the ship production schedule.

#### **On-unit Outfitting**

The assembly of components into package units constitutes on-unit outfitting and this is the earliest outfitting stage (Storch, Hammon, and Bunch, 1988, p. 81). The best place for this activity is an indoor shop. Shop work provides a controlled climate with good lighting, access to tools, and the opportunity to work down hand. Work may be grouped according to the type of production machinery and processes required. The ATC modules are examples of interim products designed for on-unit assembly. They are expected to be treated as purchased material, or to be built at a (preferably indoor) manufacturing facility at the shipyard. After being assembled on-unit, the ATC modules may be used as components for the assembly of larger package units, or they may be designated as final outfit units and then installed on-block. For this study, the ATC package units were scheduled to be assembled on-unit and subsequently installed (inserted) on-block.

#### **On-block Outfitting**

Outfitting on-block is the assembly of outfit components on a structural subassembly or block, prior to its erection (Storch, Hammon, and Bunch, 1988, p. 81).

#### **On-board Outfitting**

Outfitting on-board includes, and theoretically would be limited to, the connection of units and/or outfitted blocks, final painting, and tests and trials. In practice, however, this stage includes some installation of outfit components, in a hull at a building position or outfitting pier, which are not incorporated on-unit or on-block.

### **SCHEDULE INSERTION POINTS**

There may be several opportunities for inserting ATC package units into the ship construction schedule. The designs of the four modules are subject to change, but they are likely to remain suitable for on-unit assembly followed by installation (insertion into the ship construction schedule) during the on-block stage of construction. For this study they have been scheduled for insertion into the blocks at the start of the on-block outfitting stage in the block erection schedule. Assuming that the ATC modules are final units and that they are not used as subassemblies for further on-unit outfitting, this is a conservative approach because the beginning of on-block outfitting is the earliest possible point that final package units might be required in order for other work to proceed. When the design becomes more firmly fixed, the degree of precision in planning and scheduling by the shipyard can increase. At that time, a later insertion point may be chosen for reasons such as the need for the block to be in an upright position, a requirement to land large, heavy equipment by overhead crane, late delivery of material, or a need to install a module after blasting and painting.

### **ORDERING LEAD TIMES**

Modules and vendor supplied components should be ordered for just-in-time delivery, with a prudent amount of positive slack time to allow for contingencies, especially for items on the critical path. Unnecessarily early ordering is wasteful because carrying costs are increased and module or component purchasing expenses are incurred earlier, and late delivery is costly because it causes rework in planning and production. Timely material identification,

ordering and receipt is therefore a prerequisite for efficient ship construction.

Order scheduling depends on accurate lead time estimates. Ordering lead time for modules is the time between award of the purchase order and the ATC module insertion point. This study does not include an analysis of shipyard actions prior to purchase order award. There are five types of activities to consider.

a) Manufacturer's planning: design, technical data approval, and other planning functions.

b) Material lead time from subcontractors: material and parts procurement, especially for components on the critical path.

c) Manufacturing, testing, and preparation for shipment.

d) Shipping time.

e) Shipyard receiving, inspection, and preparation.

The overall duration of the five activities is the ATC module ordering lead time. Subtracting this from the module insertion point gives the date that the module purchase order should be awarded to the vendor. This date does not include consideration for additional lead time that may be needed if the order is large enough to exceed the capacity of the manufacturer(s). In addition to material ordering lead time, some additional time before the order point will be required by the shipyard for acquisition planning activities. Shipyard actions which take place before the material order point are not analyzed in this study.

The information used in the module ordering lead time estimates came from the Navy's annual survey of the shipbuilding industrial base (*Manufacturing Lead Times*, 1993). This study is a planning guide based on peacetime conditions and does not include wartime or mobilization considerations.

## LSD 49 ANALYSIS

Examining the LSD 49 was the first step in determining the production impact of the ATC standard outfit package units.

## Locate Compartments Where ATC Modules Could Replace Existing Systems

Compartment completion schedules and general arrangement drawings were studied for the functions of each compartment. All compartments where planned ATC modules could fit were tagged for analysis. As an example, the LSD 49 general arrangement drawings show a sanitary space in compartment 02-56-4-L, in the superstructure. This sanitary space will be traced through the production impact analysis process.

## Associate Compartments With Blocks

Each identified compartment was associated with a construction block using the LSD 49 compartment completion schedule. The compartment completion schedule assigns compartment 02-56-4-L to block 430. Production planners at Avondale Industries, Inc. selected block breaks to suit their construction strategy for the LSD 49. Different block breaks could be used depending on the availability of facilities, material, or manning at the time of construction of a particular hull.

## Derive Construction Schedules

The block construction schedule, ship erection schedule, and other documents were used to derive a construction schedule for each block containing an ATC module, from start of fabrication to erection. Not all schedules were referenced to the same milestone, so all were normalized to start of construction of the ship. Start of construction is a major milestone, and is usually defined in naval shipbuilding contracts to occur when the first structural pieces are cut. The start of construction was estimated at six months before keel laying; this was the approximate average of the LSD 49 class ships built by Avondale.

The block erection and outfitting schedule showed the following sequence for block 430.

a) Pre-fabrication begins 5 months after start of construction.

b) Fabrication begins 6 months after start of construction.

c) On-block outfitting begins 8 months after start of construction.

d) Final assembly begins 10 months after start of construction.

e) Erection begins 15 months after start of construction.

This information is plotted in Table II as the "Duration of block construction" bar for Item No. 3.

## Identify Start of On-Block Outfitting as Module Insertion Point

The first scheduled on-block outfitting point of each applicable compartment of the LSD 49 was selected. These module insertion points are shown by a letter "I" in the block construction bars in Table II. On-block outfitting of block 430 began eight months after start of construction, and this point is marked on Table II with an "I" at Item No. 3.



## EXTRAPOLATION TO THE LPD 17

The next phase took the LSD 49 block construction durations and module insertion points, and applied them to the LPD 17 plans.

### Identify LPD 17 Compartment Locations

LPD 17 compartment locations for the common modules were identified, and each such compartment was associated with a construction-block. The preliminary general arrangement drawings were used. The locations for fire pump, reverse osmosis and steering gear common modules were proposed by the ATC Program (*Modularity*, 1993). Sanitary space common module locations were not yet fixed, so the two potentially applicable compartments that were the earliest and latest in the notional block erection schedule were selected for analysis in order to bracket the problem. These were blocks 2241 and 2293.

### Estimate Construction Schedules

Construction schedules for the LPD 17 blocks were estimated using the LSD 49 block construction schedules as a guide. For each LPD 17 block, the start of on-block outfitting was identified, and this was used as the ATC module insertion point, as was done for the LSD 49 analysis. The major milestones and construction schedule of the LPD 17 were taken to be the same, or slightly longer than, the LSD 49. This is a conservative estimate. The notional LPD 17 erection schedule (*LPD 17 Hull Erection Study*, 1993) showed the block erection points. The blocks were then assigned the same, or a slightly longer, construction schedule as the corresponding block from the LSD 49. Longer schedules were used when the LPD 17 compartment or block configuration was more complex. Within these block construction schedules, the insertion points for the ATC modules were located at either the same point as for the LSD 49, or at a prorated point if the LPD 17 block construction schedule was estimated to be longer.

Block 2241 was scheduled to begin fabrication approximately six months after start of construction, and erection was estimated at fifteen months after start of construction. The start of on-block outfitting and therefore the insertion point of the sanitary module into this block was then estimated at eleven months after start of construction. These points are shown in Table III.

### Estimate LPD 17 Lead Times

The sanitary space module design was examined and potential long lead components were identified. These are non-stock items that have to be fabricated or manufactured to order, and are listed in Table IV. For each module, two months was allowed for manufacturer's planning, and this is shown as Item 1, Table V. This is probably conservative, because the ATC modularity is intended to streamline this process. The longest lead times, five months each for the relief valve and exhaust fan, determined the duration of Item 2, material lead time from subcontractors, on Table V. Item 3, manufacture, test, and prepare for shipment was estimated at four months. Items 4 and 5, shipping time and shipyard receiving, inspection, and preparation are variable and one month was allowed for each. The same process was carried out to calculate the lead times for the other three ATC modules.

The total ordering lead time for the module is not equal to the sum of the individual sub-process lead times described above because of task overlap. For the sanitary module, there are three months of overlap so the module ordering lead time is ten months rather than thirteen, as shown in Table V.

The purchase order award date was determined by subtracting the estimated material ordering lead time from the module insertion point. The order award date is shown by an "O" in Table VI.

The insertion point for an ATC sanitary module to be placed into block 2241 of the LPD 17 notional build strategy is eleven months after start of construction (Tables III and VI). The sanitary module purchase order award date is estimated at ten months prior to that (Table V). The purchase order award date is then one month after start of construction. This is marked on Table VI with an "O". This estimate is intended to be conservative and if it is, then the actual purchase order award dates could be later. If, for example, the modules are purchased from existing stock, or if they become a commodity item and are manufactured using efficient series production processes, the delivery times could be significantly shorter and the ordering lead times reduced correspondingly.

## CONCLUSIONS AND RECOMMENDATIONS

The results of this study are shown in Table V, "ATC module ordering lead times", and Table VI, "Order points for ATC common modules in LPD 17". The module ordering lead times chart is useful for ATC systems engineers. It shows that material lead time from sub-contractors is the critical item to address if module lead times are to be reduced. The module

ATC Sanitary Space Common Module	
Component	Material Lead Time
Resiliently mounted urinal	2 weeks
Resiliently mounted water closet	2 weeks
Overhead lighting	4 months
Over mirror lighting	4 months
Door, non-watertight	4 months
Bulkhead panels	3 months
Heater (hot, fresh water)	2 months
Exhaust fan	5 months
Reducing valve (flushing water)	4 months
Relief valve (flushing water)	5 months
Steel plate for deck	2 months

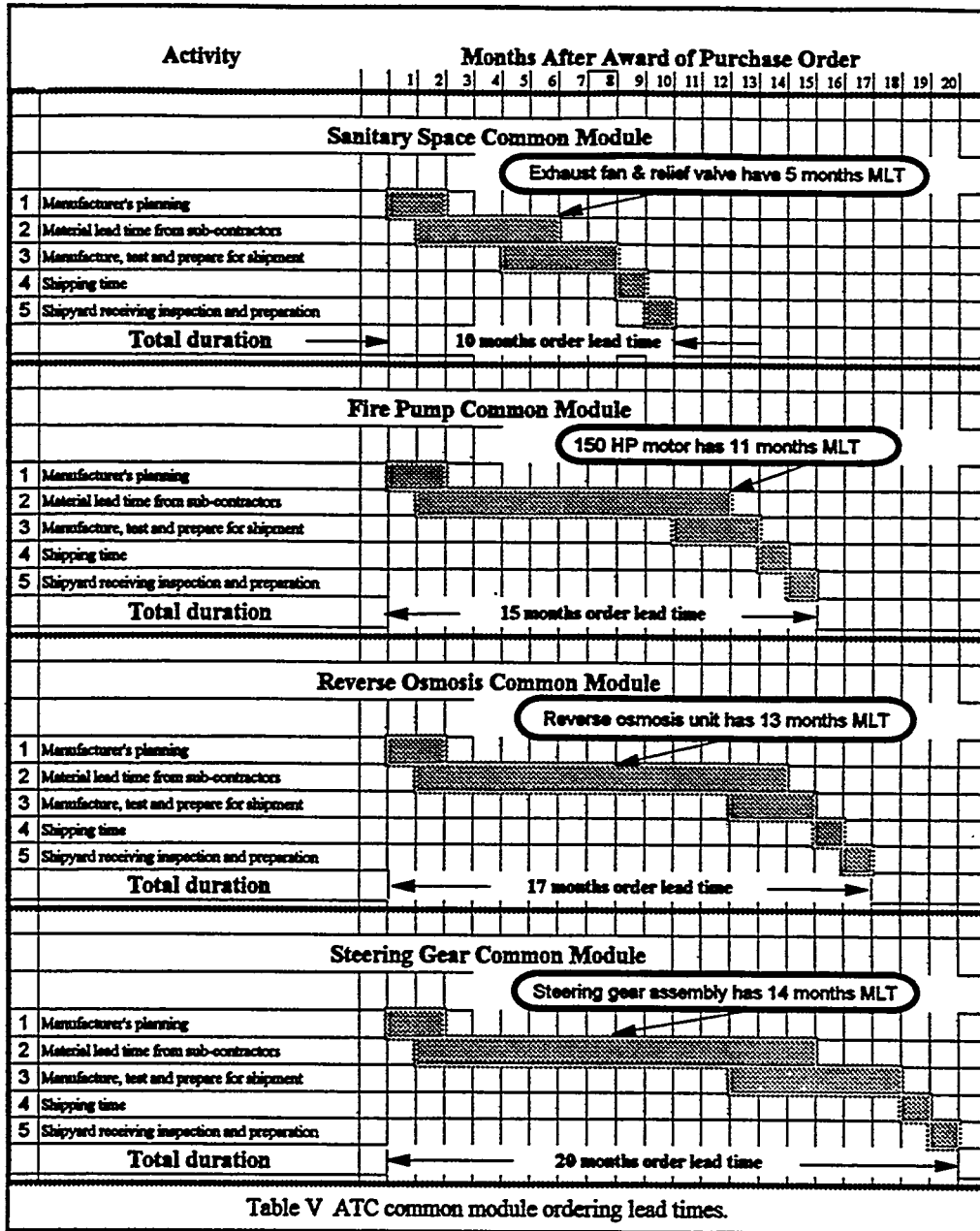
ATC Fire Pump Common Module	
Component	Material Lead Time
1,000 gpm titanium (prop) fire pump	10 months
Motor 150 HP	11 months
Motor controller 440 AC 1 speed	7 months
Automatic Bus Transfer (ABT)	6 months
Gage board	1 month
Casualty power terminal	1 month

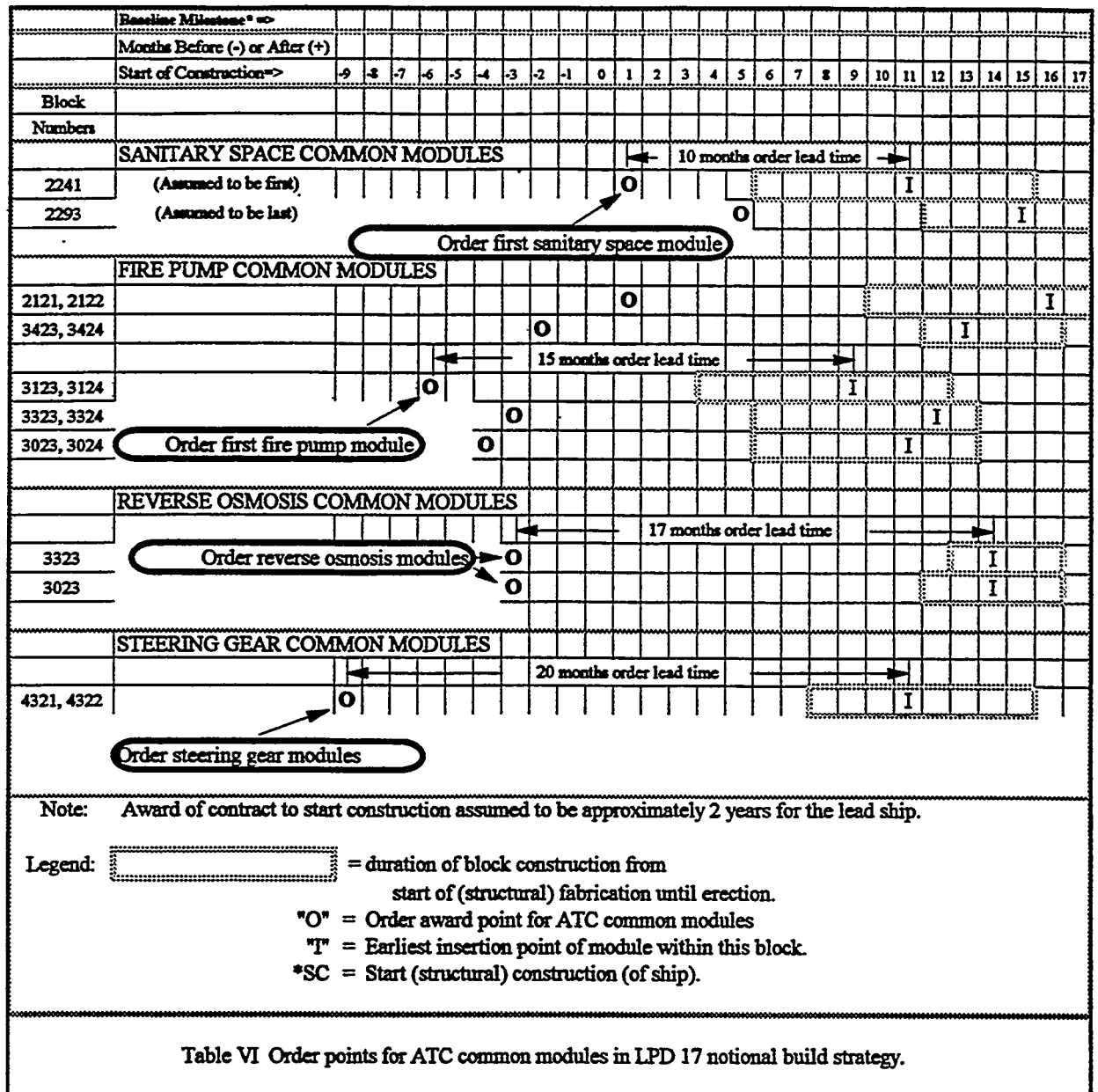
ATC Reverse Osmosis Common Module	
Component	Material Lead Time
Reverse osmosis unit	13 months

ATC Steering Gear Common Module	
Component	Material Lead Time
Steering gear assembly*	14 months

\*Includes pump, motor, hydraulic fluid stowage tank, ram, tiller, and angle indicator.

Table IV Material lead times from sub-contractors for selected components.





With the greatest standard commercial parts content the sanitary space module, is the module with the Shortest lead time.

The order point chart, Table~shows that the earliest order award point for any of the four ATC Standard outfit modules occur's nine months before start of construction. If three months are allowed for the shipyard's pm-purchase order activities such as the bid process collection of vendor furnished information another actions, then the shipyard must begin the module procurement process twelve months before the

Historically, for lead ship of a class similar in size and complexity to the LPD 17, construction has started approximately two years after award of the shipbuilding contract Twelve months prior to star tof construction is then equivalent to twelve months after contract award, and so there is twelve months of slack time available before any module procurement action must take place. It is reasonable to conclude, then that incorporation of the ATC standard outfit unit modules will have no adverse impact on the construction of the LPD 17 class lead ship.

This one year buffer is based on historical data on the time needed to achieve construction start-up. Maintaining existing schedule norms is not the goal of the LPD 17 design for production; significant reductions are sought. The ATC module lead times in this analysis, however, werealso based on historical performance and the ATC program through its streamling of the design, planning material ordering and production tasks for its module system intends not only to support but also help drive the reductions in overall ship procurement t i m e s .

There should be few problems in the implementation of the ATC standard outfit package unit system All domestic shipyards capable of building the LPD 17 are familiar with the use of outfit package units similar in planning requirements to the four ATC modules studied so the modules introduce no unproven production technologies.

The aspects of ship procurement which have a **potential impact on the results of this study are the** contacting and construction processes and the capabilities of the shipbuilding industrial base. If the lag between award of a shipbuilding contract and the Start of construction is reduced to less than twelve months, then it will be necessary to make **corresponding gains in the speed of module procurement. The capability of the shipbuilding industrial base becomes factor** if all of the module manufacturers are overloaded by large orders, in which case the material ordering lead times could be prolonged. Furthermore, if the construction strategy

differs significantly from the baseline LSD 49 process used here, then the insertion points could be earlier. Investigations of these issues could be the subject of follow-up study.

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# Robot Technology in the Shipyard Production Environment

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## ABSTRACT

This article presents the current status of robot technology in the shipyard production environment. We focus on a case study in which a computer integrated and robotized web and component line is presented. This production line will be fully operational mid-1995.

An overview has also been included of the most relevant technologies with regards to robot production in the shipbuilding industry, and how these technologies contributed to the introduction of robots in shipyards. The need for integrating the robots with the rest of the shipyards' material flow, computer systems and organization is first discussed, while a brief survey of emerging technologies which may be useful for the shipbuilding community is presented afterwards.

## INTRODUCTION

International shipbuilding is in a process of change. The established order of shipbuilders, with Japan being the major builder and South Korea being in second place building predominantly "simple ships", is changing. Japan is experiencing cost problems due to high labor costs and currency depreciation. South Korea is taking the opportunity to increase capacity and to improve productivity. At the same time South Korea is building more complicated ships such as LNG tankers and container vessels. The combined market share of Japan and South Korea is, however, likely to remain at approximately 65%.

The rest of the market is experiencing rivalry from established Shipyards in Europe and China, with newcomers from Russia and Ukraine entering the field. In addition, the US shipyards are making serious efforts to enter the commercial shipbuilding market to compensate for the reduction in naval work. With relatively favorable labor costs and a determined effort,

it is probable that they will experience some degree of success.

To some extent the competition is between low labor cost countries who are investing in low to medium level of technology to improve their output and quality, and the high cost countries who are investing in high technology. The days of the simple shipyard consisting of a berth and some cranes is coming to an end, even in countries with low labor cost. Manhours per tonnage of steel and the time in dock must continuously be reduced as has been done in the last hundred years, see Figure 1.

In this article we will look at some of the "High Tech" developments now being implemented. The introduction of robotics in the shipbuilding industry is now gathering momentum after several false starts. It is being recognised that the robot itself is only one of many tools required for the introduction of CIM (Computer Integrated Manufacturing) in the shipbuilding industry. However for the robot to work the dimensional accuracy of the pieces to be welded by the robot must be exact. The extensive use of robotics in the steel fabrication requires heavy investments in the material preparation of plates, profiles and manufacturing of subassemblies. The successful introduction of robots to the shipbuilding industry has been made possible due to the technological developments over the past three decades. The challenges and obstacles have been many. The main challenge can be formulated as:

How do we efficiently use robots in small or one part production series in an environment with a low degree of dimensional accuracy of both the raw materials and the subassemblies?

The dimensional accuracy of the steel profiles from the steel mills was, and still is for some yards, a problem for automatic manufacturing. A human operator has no problem adapting his welding or cutting job to inaccuracies in the dimensions of the

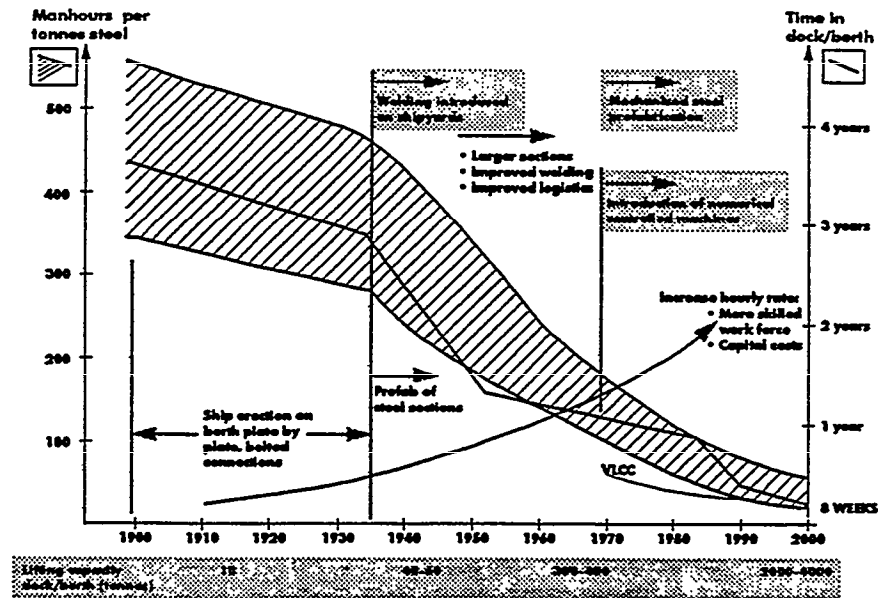


Figure 1. Global trends in shipbuilding in the last 100 years.

material. However, this is a problem for the robots. There are two ways to compensate for this. First, the yard can install milling machines which correct the dimensional deviations so that accurate profiles are used in the production. Second, we can equip the robots with sensors so that the robots can adapt their programs to the actual instead of the planned profile geometry. The disadvantage with the first approach is that it is costly, while the second approach may reduce productivity. The robot can weld plates with distortions from its designed geometry, but the amount of manual repair work and adjustment of the robot program may also reduce productivity. A combination of these two methods is recommended as a compromise. However, some yards have a third option. They can buy high quality profiles with the necessary dimensional accuracy directly from the steel mill. No or little milling is necessary and the robot uses very little time searching. There exist yards which are directly connected to the steel mills' ordering computer, so that orders can be placed directly. The delivery time is down to less than three weeks and the dimensional accuracy is very good.

The yard will achieve high productivity from its robot production lines if it focuses on dimensionally accurate production. On the other hand, robots produce with very accurate dimensions, so that this is a self-fulfilling situation. A robot-based profile cutting line is a good starting point for introducing robots at shipyards since accurate cut profiles are, together with plates, the starting point for all the subassemblies. It is important to notice that the key to dimensional

accuracy, which forms the backbone of the efficient shipyard, lies in a detailed practical knowledge of the application of the shipbuilding technology and not in robotics, CAD or any other more narrow technology.

The other major challenge is how to efficiently program the robot system. We use the term robot system and not robot since the whole production line must be programmed, not just the robot manipulator itself. The material transport, the printing device, the robot's external axes, the robot motions and the robot tool must all be programmed in a coordinated manner. This programming task must be performed efficiently since we have small series production, and most robot programs are used only once or twice. A natural starting point for the robot program is the geodetical data which already reside in the yard's CAD (Computer Assisted Design) system. The problem is now how to transfer design data in CAD format to production data in a robot source code format. This can be achieved in several ways and is discussed later in this article. However, this paper focuses the reader's attention on a method called macro programming. Macro programming builds on the fact that most tasks a robot performs are similar to one another. It can almost be said that the robot performs mass production on a smaller scale, a so-called task scale, see Figure 2. This fact is taken into consideration in macro programming. The importance of having an efficient off-line programming system should be stressed. A skillful off-line programmer can produce off-line robot code for a complete ship as it is being built.

A third issue that is important to consider design for production. The term design for production indicates that the production process is taken into consideration already at the detailed design phase of the production process. The detailed design engineer must know the capabilities and the limitations of the production equipment in order to be able to optimize yard productivity. Compromises with respect to material selection, dimensions and detailed layout may be necessary in order to achieve higher productivity and a lower cost for the ship from an overall perspective.

Several yards have successfully implemented the design for production principle in their CAD offices, and, as a result, have substantially increased the efficiency of their off-line programming process and robotized production lines.

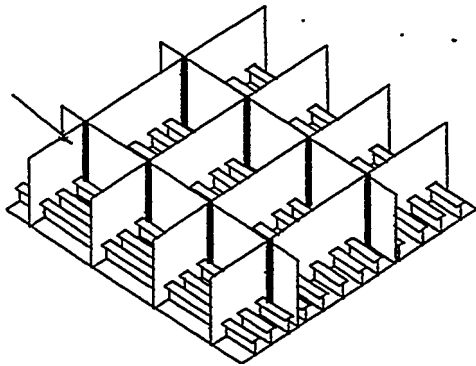


Figure 2. Example of robot welding macros for double bottom assemblies.

## Contents

Section two introduces the reader to the present situation regarding robots in the shipyard production environment. Section three presents the current status of some key technologies for robot production. Section four stresses the point that robots should be treated as integrated parts of a production system and not as stand alone products. Section five presents an example of a robotized production line for the manufacturing of web and components. All the corresponding software and hardware components are discussed. Section six presents some work which may result in promising technologies which the shipyard production environment may benefit from.

## PRESENT STATUS - A CHALLENGE

It is possible to divide the shipyard industry into three categories the yards which have no experience whatsoever with robot production systems, the yards which unsuccessfully employ robots at their yard, and

the yards which successfully employ robots in their production. Only the two latter categories will be discussed in this article.

At shipyards which unsuccessfully employ robots in a stand alone production cell for welding or cutting small parts in small to medium sized series, the robot is usually programmed on-line by the "lead through" or "tech in" technique-no interface to the CAM (Computer Aided Manufacturing) system is present or needed. Material infeed and outfeed is usually manual or semi-automatic. This category of robot production units lacks two essential elements to be efficient: first and foremost, an efficient programming system for the robot and second, an efficient integration of the robot with the rest of the yard's material flow. This category of robot installations was installed in yards in the 1980's when robot manipulator technology had matured. However, installations occurred without a corresponding level of maturity on the off-line programming and system integration frontier. The installation of these robots was met with an unrealistically high expectation level from the production people. When expectations were not met, due to the lack of integration of the robots with the rest of the production at the yard, the production people sensed failure.

Shipyards which have successfully applied robots in production, have used a totally different approach. The installation and planning of the robot installation have often been carried out by personnel who are enthusiastic with respect to this new technology. The management has been committed to the introduction of robots at their shipyard, and the robot installation and corresponding software has often been developed in co-operation with an academic institution and fully or partly sponsored by national research agencies. This category of robot installations usually takes place at large shipyards, and the robotized production lines are frequently integrated with the rest of the yard's production. The link to the CAD/CAM system is customarily a non-standard solution which is tailor-made for this particular CAD/CAM system, shipyard and application. The same observations are also true for the shop floor control System if the yard has one at all. Functions such as reporting and logistics (material tracking stock yard control, etc.) are, if they exist at all, usually also tailor-made for the specific shipyard. The robots are customarily programmed in an off-line manner with a non-standard programming tool, either macro-based or else based on a VRI system (Visual Robot Interface). Several yards have successfully applied this approach, and up to 20% of the welding meters can realistically be expected to be cost efficiently welded by robots with these systems. There

is, however, growing concern regarding the increasing costs associated with the maintenance and upgrading of the yards' various software packages. These costs can be reduced in two ways. First, costs can be reduced by buying proprietary software from a company which sells production equipment to more than one yard. The development and upgrade costs are in this way shared among the various yards. And second, by using standard file formats such as the graphical exchange format IGES (Initial Graphics Exchange Specification), (IGES 1991), the production model STEP (Standard for External Representation of Product Data), (Owens 1993) or an appropriate neutral robot programming language, see for instance (DIN 66312 1993).

## **THE CURRENT STATUS OF ROBOT PRODUCTION TECHNOLOGY**

This section is included to make the reader aware of the current status of some of the most important technology elements of the robot production technology.

### **CAD/CAM systems**

A fully computerized production system includes several modules, with each module taking care of different steps within the process of creating a product. Generally, the system may be divided into two main parts; one taking care of the production process, whereas the other takes care of the organizational part. The former part is discussed in this section.

The term CAD systems is used for a computer system which is used for the design and drafting. In addition, engineering calculations may be performed. The earlier CAD systems had limited capabilities, but as the hard- and software systems have evolved, a broader range of possibilities have emerged. The increased level of model and drawing complexity has led to an increased amount of data to be handled by the CAD-system. The contents of these databases may be divided into various parts: first, the technological data containing data about geometry, tolerances, material, etc.; second, the organizational object related data such as name, weight and lot number; and third, the data related to the drawing such as scale, drawing number and formats. The CAD database is an integrated part of a production system containing information that may be used as input for programming the production equipment. Some data processing is required to put the available data in an appropriate format for the production machines.

To increase the level of automation process data may be integrated with the data-flow sent to the

production equipment. Process data is information about the manufacturing process, such as welding speed, shielding gas pressure, painting accuracy or grinding parameters.

The CAM system takes care of the computerized control of the manufacturing process. This implies direct control of production equipment as well as management of the materials and tools to be used by the production equipment. Data entry and logging of process data may also be reconsidered a part of a CAM system. The input to the CAM system may be files from the CAD system, along with process information. Any required transformation of CAD data into a CAM appropriate format is done by the CAD system. For instance the representation of data in an ESSI (ISO 6582) format is common for many shipyards. The ESSI format, which is a standard for numerical programming of cutting machines, is generated by the CAD system. The CAM system may then use the information in this file for control of CNC-equipment.

### **Robot Manipulators**

Robot manipulators have been developed from special purpose spot welding manipulators tailor-made for the automotive industry into multipurpose robust, flexibility, and easily programmable manufacturing tools. Today's robot manipulators are inherently more robust, reliable, and flexible compared to those used 25 years ago. Advances in control technique, robot drive technology, mechanical design, computer engineering and software have provided the robot industry with the necessary technology to manufacture robot manipulators with a level of flexibility and adaptivity which make them applicable for the shipbuilding industry.

A robot can be described as a programmable multi-function manipulator designed to move material, parts or specialized devices through variable programmed motions for the performance of a variety of tasks. Here, a manipulator could be any structure with controlled joints and connecting links to support the physical functionality that is required to perform a given task. In an industrial environment or at least in a large number of industrial processes, a manipulator is often an anthropomorphic (humanoid) mechanical arm, with some resemblance to a human limb. In industrial applications such as arc-welding, deburring, painting, gluing, handling and assembly, six-DOF (Degree Of Freedom) manipulators are often used. Six DOFs are necessary to facilitate the possibility of reaching any position and orientation within the manipulator's working range. Each DOF or axis is controlled by a servo drive, and the complete robot is

automatically controlled by a designated computer. The input to the computer is the robot program, and the output is usually the command signal to each of the servo controllers.

Current industrial robot systems have reached a very high level of sophistication regarding performance, reliability, and robustness. The robots are sophisticated, flexible and reliable enough to be applied to the shipbuilding industry, a well-recognized fact in parts of the shipbuilding community.

### Off-line programming

Two fundamentally different approaches, on-line and off-line programming are employed in robot programming. Only off-line programming will be discussed in this section.

Off-line programming is basically the same as computer programming. The robot's motion is programmed on a computer, graphically or by using a computer language without disturbing the robot. Hence, the robot can undertake a planned task while the operator programs the next one.

In shipbuilding, the input to the robot program usually consists of drawings on a paper or on a CAD system. There are three alternatives with respect to the link between the CAD system and the robot program complete manual programming such as macro programming; semi-automatic programming with the help of a VRI system or fully automatic programming where the CAD files are automatically processed on a computer with a complete robot program as the final result.

Complete manual robot programming is performed by entering the appropriate high level robot commands manually into a computer on the basis of a drawing. The advantages with manual programming are the low costs and complexity of the software and ease of use. Many shipyards successfully use manual programming. It is also relatively easy to upgrade this system to a more advanced configuration at a later stage if desired. This should be the entry level for shipyards with limited experience in robotized production.

The input to the VRI tool is the CAD files containing a complete product model, or parts of one. The output is robot programs in a certain format for example in a neutral robot programming language, robot control commands, or macro data files. VRI, in the traditional sense, works as follows. The robot, necessary peripheral equipment, and the work pieces are displayed on a high resolution graphical computer screen. The robot and the peripheral equipment are part of the VRI software while the work piece is

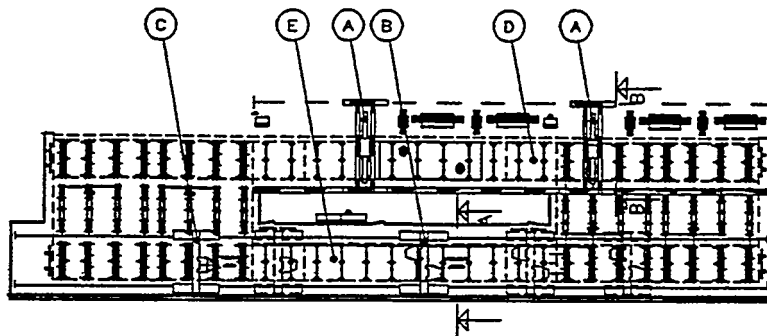
displayed by **importing** the CAD file. The CAD file has to be in an appropriate format and converted to a graphical image on the screen. The operator manually moves the simulated robot on the screen over the desired welding or cutting trajectory by using a mouse. The corresponding robot commands for moving the actual real-world robot are then generated by the VRI system. The robot program can now be downloaded to the robot for execution of the

desired task. The advantage with this approach is that, compared to customized systems, it provides the user with a relatively flexible and inexpensive bridge between the CAD system and the robot production line. The disadvantage is that the software and especially the hardware maybe expensive compared to manual macro programming systems. The efficiency of this way of programming the robot may also vary between the different products and applications.

CAD files containing a complete product model, or parts of one, are also the input for a fully automatic robot programming system. The output is robot programs in a certain format a neutral robot format, robot control commands, or macro data files. The robot programs are generated automatically without any human intervention. Process information, such as welding or cutting parameters, must reside in the product model if no operator interaction in the computer programming process is required. This form of robot programming is usually tailor-made for the actual installation. That is, the program is specially designed for this particular application, CAD software, and type of robot. Robotized profile cutting lines **usually use this approach combined with macro programming.**

The advantage with this approach is that it is very efficient. The disadvantage is that it is difficult or expensive to use the same program for different applications. Thus different programs are used for different types of robot operations. The program is usually customized for the specific application so that the initial programming expenses are high.

The point is that the three technologies described above have reached a level of maturity which make them applicable to the shipbuilding industry. However, this alone is not enough. The knowledge and technology involved in integrating these technologies into working and profitable production systems is new and, for some applications, untested. The next section discusses the importance of the integration aspect, while some key problem areas and challenges are pointed out.



**Figure 3. General arrangement of robotized web welding line, A: stiffner mounting gantry, B: double robot gantry, C: single robot gantry, D: tack welding area and E: robot welding area.**

### SYSTEM VERSUS PRODUCTS

It is important to note that a working robot production system must be integrated with the rest of the yard's production environment. It is also important that the robot interacts with the rest of the yard's material flow. For instance, efficient material infeed and outfeed to a robot manipulator is vital to achieve a high degree of utilization of the robot production unit. The costs related to the material infeed and outfeed systems are usually higher than those for the robot manipulator with corresponding hardware and software. However, it is vital to incorporate this investment into the project when the rest of the robot production unit is purchased in order to achieve a justifiable return on investment. For most shipyards, a stand alone robot manipulator without the necessary support equipment will be a bad investment and create prejudice against robot investments. On the other hand, an efficient robot production system fully integrated with the rest of the shipyard will be the showcase for the yard when presenting the yard to ship owners and investors—the investment in the robotized production line will be justifiable and sound.

Another major cost item in the investment budget for robotized production lines is the computer software. The software contains functions such as robot programming control of the material infeed and outfeed, marking, progress reporting, and sending status and quality data back to the work preparation office. The off-line programming of robots is a particularly challenging task. However, an efficient implementation of this software can increase yard efficiency in a way that easily justifies the investment. An efficient off-line installation with a skilled off-line programmer can take care of the programming job of a complete ship while it is being built. This does, of course, assume that the yard has a good library of robot macros and an effective link between the cdl-line system and the yard's CAD/CAM system. Some readers

from production may ask themselves: "What about my particular needs? I only have my drawings on paper." This may be the case for some yards which build naval ships, for instance. The macro based off-line programming technique can also be efficiently applied to this category of production. An experienced shop-floor operator can easily keep several robots fully occupied with job tasks by manually entering macro programs to the robot control system. This is achieved by utilizing the paper drawings and the yard's library of cutting or welding macros. It is important to keep in mind that on a daily basis the operator normally uses 10-25 robot macros while a complete large macro library contains on the order of 100-200 robot macros.

It is very important to take into account a complete system when an investment in a robotized production line is being considered. The analysis must at least include items such as: material infeed, outfeed, computer hardware, software, a macro library, training and a software maintenance agreement. An analysis of how the new production equipment interacts with the other production lines should also be performed. Simulation is a useful tool in the analysis. Factors such as transportation requirements, personnel resources, necessary ground space, etc. should be included.

### EXAMPLE OF AN INTEGRATED ROBOT PRODUCTION SYSTEM

In this section, a description of a production system for manufacturing of webs and components for tanker vessels, bulk-carrier vessels and container vessels is given. Such a production line is currently being installed at a yard in Europe by TTS International AS.

The presentation given in the following section does not aspire to be a complete description of the production system. It merely indicates the capabilities of this new but commercially available computerized and robotized production system. The web and

component line is designed for manufacturing of webs with stiffeners, restricted in terms of physical dimensions to a maximum dimension of 3 by 16 metres. The layout in Figure 3 indicates the various system components. The production line is constructed IRB2000 robots with S3 controllers. Two external axes are augmented to the robots, the position of the gantry and the position of the robot base along the gantry, see Figure 4.

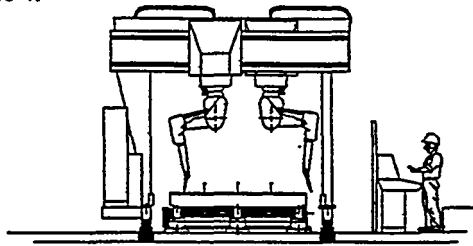


Figure 4. Robotized web welding station.

#### Capacity calculations and operator requirements

To give an example of the capacity of this line, it produces all webs and components for about four 160.000 tdw. bulk-carrier, tanker vessels or 3000TEU container vessels a year with 3-5 operators. Compared to manual welding or semi-automatic welding of the above mentioned products, this line has a substantially higher productivity. For a fully manually operated line with similar capacity, up to 20 operators are required. This figure is reduced to about 12 with a semi-automatic production line, while the robot line only requires about 3-5 operators. All the above calculations are based on a 230 day 17.5hr /2-shift cycle. These figures are largely affected by the complexity of the products to be processed. The above figures are based on low-complexity webs and components, which partly favors semi-automatic production. However, the robot production line is a multi-purpose production system and when the complexity and variation of the production increases, which currently is the case for several yards, the manual or semi-automatic alternatives require increased operator interference, while the robot production line is not affected by such complexity increases in the same way.

The work preparation tasks, that is the off-line programming of the robots, roughly require the services of one operator who is included in the total personnel requirement figure above.

#### Work Preparation

As illustrated in Figure 5, the total computer system layout of an integrated computer system in a

around a transport system made up of a horizontal matrix conveyor system running in an endless loop, **carrying pallets for the production objects. One double-robot and one single-robot-gantry** are positioned over the transport system. This line utilises ABB shipyard environment involves several system components at various levels. Note that the system presented here is one particular solution for the integration problem of this production line.

There are several ways and different strategies for conversion of CAD-data into a representation suited for generation of executable robot code. It is required that the operator tasks related to the process of transforming data from CAD data to robot code are reduced to a minimum. In general, the operation involves high-level quality control, inspection, and verification of the computer system performance, which today is a task no computer can do better than a trained human operator. Since the need for human interaction is reduced to a minimum, and one central site for these tasks can provide executable production programs for several production lines, the work preparation office is centralized and located in conjunction with the design department.

Three steps are involved in the work preparation.

Step 1. Design for production. The CAD-**operators and designers are creating a model of the ship by utilizing functions in the CAD-system.** The detailed design should take into account limitations and capabilities of the production system that will be used. The final result from this process is a computerized representation of the ship. Then, through so-called post-processor functions, the model representation is exported from the CMD-system and stored as a data-file on the yard's computer system. The post-processor solves topological conflicts and sorts the various CAD data into an object representation suitable for further processing by the off-line programming system.

Step 2 Operations at the central work preparation office.

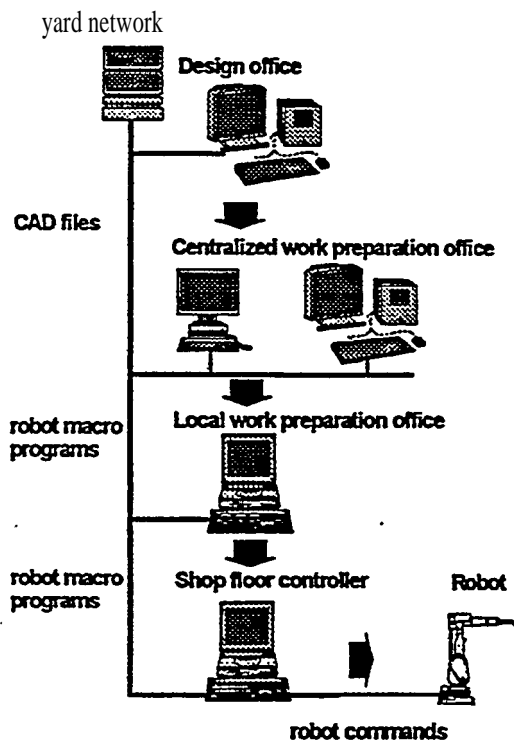
The next step is to perform the tasks in conjunction with the conversion of the data, and to create of input code for the robot production systems. By using a dedicated computer system specially developed for tasks of this kind, the data file containing the CAD-model is imported to the workstation-based system. Here, the assembly or unit released for production is displayed in a synthetic environment, visualizing the production line itself with the object to be processed. By using dedicated functions within the system, the

operator can initiate semi-automatic functions whereby

the model representation and create a data file containing those data which the robot system requires to be able to automatically generate the executable robot programs.

If a CAD representation is not available, an off-line manual assignment and scheduling of parameters to the chosen macros will take place. This method is practiced successfully at several yards and is under installation as a back-up method at this particular work preparation office.

For a completely automatic link to exist between the CAD system's post processor and the robot production line an automatic conversion from CAD drawings to robot programs must occur without any human intervention. This link is implemented for the robotized profile cutting line at this yard. Note that all the work preparation tasks for the entire yard take place at the centralized work preparation office.



**Figure 5. Computer system arrangement for off-line programming.**

Step 3 From work preparation to shop-floor.

The third and last step in the conversion can be activated either at the central work preparation or at the local work preparation office, with the latter foreseen as the usual routine. Now the final robot programs will be created or compiled. This leads to the

actual executable programs for the robot production system with additional peripheral equipment. At the local work preparation level the operators can select the input files for the robots on the basis of production orders from the planning systems and initiate the final automatic creation of the robot program. This task may, as indicated above, also be performed at the central work preparation level since similar functions are available there. The software for these functions run on PCs, and the cost for redundancy is by far compensated for by the versatility of the total system. From here on, the control of the robot operation is performed automatically at the production line itself, with possibilities for the robot operator to override and edit functions according to available production items or jobs present at the line.

All the types of systems referred to above use the macro technique for robot programming. The basic idea is that all the robot tasks that are foreseen to be required for a given production line are supported by a set of almost complete robot programming that is, semi-complete in the sense that the program files only need a few parameters characteristic for the object to be processed, the so-called macro methodology. In general, one type of production line will often repeat the same types of robot programs, only with small variations. This is described earlier in this article as mass production on a task level.

The production line described in this section has the Capabilities of all the solutions listed above. In sum, this robot programming environment incorporates a combination of some of the most desired and powerful functions that are available from the separate systems.

Figure 6 indicates that there are several available strategies and system solutions for the actual conversion of the data from the CAD-system. A variety of robot vendors and system houses have developed different systems that all have special advantages over one another, but no system today is superior in terms of completeness.

#### Shop floor operations

The web and component line described in this section is matched with the integrated computer system described in the previous sections. This production line is the implementation and end result of the efforts that have been made to establish an integrated system that not only works on a theoretical level, but also utilizes the information exported all the way from the CAD-system to actually and physically produce the items that were initially designed. The following



paragraphs give a general description of the material requirements and the modes of operation.

**Transport system.** The transport system is made up from a horizontal matrix conveyor system, running in an endless loop, carrying pallets for the production objects. This system connects the onload and tack welding side of the production line with the robot welding areas on the opposite side. The control of the system is divided between the robot systems and the operators at the onload station. The onload operators control the movement of the transport system on their side semi-automatically, to give freedom for planning as well as to keep humans in charge of the operation. On the robot production side, one robot operator controls the robots. He can also control the transport system. Here, the operation is foreseen to be carried out more or less completely automatically, but the operator has full access to override and re-select movement patterns and sequencing of the robots by using manual override functions within the logistics system.

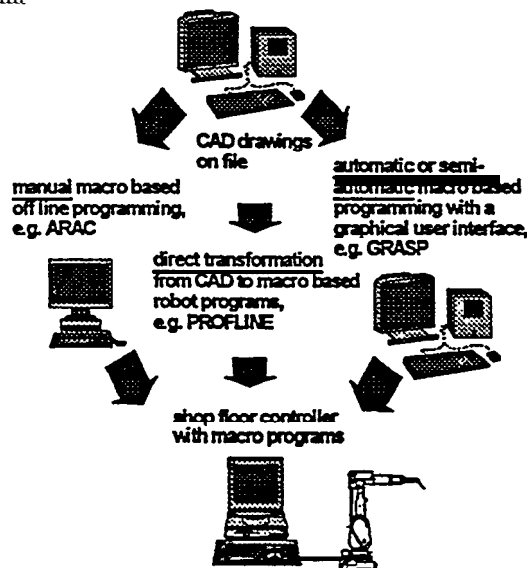


Figure 6. Off-line programming strategies.

**Loading stations.** Plates are loaded onto the pallets by use of the shop crane. Profiles are brought to the onload area in specially designed racks for easy access and pick-up. According to marked lines on the plates, the two operators mount profiles on the plates and tack-weld them manually. These tasks are performed using the stiffener mounting gantries each having a magnet manipulator, anchoring magnets and hydraulic actuators to press the profiles tightly down to the plate prior to tack welding. When one pallet is filled up with objects, it is released and automatically taken over by the robot systems.

**Robot Welding Gantries** The programs for the robot processing are, of course, already present and ready in the robot computer system, since the integrated system has created them automatically beforehand. When the robot operator enters the section identity for the objects that are located on the pallets, the robots will automatically activate the corresponding program and start executing it. During execution, the robot computer system will constantly monitor the operations and give report messages to the operator. These messages are also stored on a file for later evaluation and report generation. If, for instance, the wire-drum becomes empty, or another incident occurs requiring operator interference, the robots stop their actions, store where they are in space and in the task before moving to a safe position. Then the operator can refill or make adjustments and immediately initiate the process from where it was halted.

**Out-loading Station** When the pallet is completely processed by the robots, it is transported further to the outload buffer or the outload station, which is located at the infeed side of the line. Here, the onload operators empty the pallets by use of the same shop crane as for onload and move the webs or components over to the next transport medium. The pallets remain on the conveyor system, and continue their circulation around the system.

## PROMISING TECHNOLOGY DEVELOPMENTS

This section will give the reader insight into some of the more promising technologies which will emerge in the near future and which will be of great advantage for robot production technology. STEP, neutral robot programming languages and standard robot macro **libraries are discussed. The standard graphical file format IGES is also included for completeness, even though IGES is already an established ANSI standard.**

### Graphic File Formats and Product Modelling

As the computer hardware has become more complex, the complexity of the software has also increased. This has resulted in a growing variety of different CAD systems representing information in different ways. During the past years, several representation formats for data have been proposed, but, so far, none have fulfilled all the requirements for a streamlined CAD data exchange process. No formats have been able to represent geometrical data along with product information in an acceptable manner, though several formats have proven to be useful.

The IGES was developed for allowing data exchange between two independent CAD systems by

use of a neutral file format. The conversion to or from the neutral format, is done by use of pre-/post-processors within the CAD systems. The latest IGES version 5.1 (IGES 1991), defines a file structure format, a language format, and the representation of geometrical, topological and non-geometric product data in these formats. Earlier, IGES versions had the disadvantage of producing a large amount of data or not being able to represent solids. These problems have been dealt with in the latest versions. There were also problems using the standard, as the pre/post-processor vendors tried to maintain proprietary rights. Due to its features, IGES has become a commonly used representation for information exchange. It is also important to mention that IGES has been a base for several other interface standards, e.g. PDES (Product Data Exchange Specification) and STEP.

The PDDI (Product Definition Data Interface) is design oriented and deals with product models. The purpose of the PDDI was to be an interface between the CAD and the CAM system. The work with PDDI was, however, merely conceptual research activities and the results were used for development of the PDES. The reason for making the PDES, was to make an interface which permits the exchange of data of the entire product development and production cycle. The PDES may be looked upon as an expansion of IGES, with organization and technological data added. Regarding functionality, PDES will contain IGES version 4.0. Thus, software for converting IGES into PDES will exist. In particular, PDES uses the formal language EXPRESS for modelling product information.

STEP is an ISO activity to develop a new engineering product data exchange standard, ISO 10303. When completed, STEP will cover all aspects of a product's life cycle and all industries. STEP is based on a combination of several other common standards, such as IGES, PDDI, SET etc. It should be mentioned that STEP is not a graphics standard, but a data exchange standard, see also (Owens 1993).

To define the normative part of all information models in STEP, the formal product modelling language EXPRESS is used. EXPRESS is a product modelling language, based on entity relationship attribute models. EXPRESS has two forms; EXPRESS-G as graphical form and EXPRESS-I as instance form. EXPRESS has the advantage of being both human and computer readable.

So far it is mainly the car industry that has a STEP application protocol more or less finished for use, but the work to complete a protocol for the ship industry is already started. It is the authors' opinion that implementation of such will be of great advantage for the automation process occurring in the world's

shipyards. This is due to a more streamline integration, allowing more product related data to be transferred to the CAD system, and further to production with a minimum of human interaction.

## Neutral Robot Languages

There exist several different national and international standards for a neutral robot language: IRDATA (Internal Robot Data), ICR (Intermediate Code for Robots), IRL (Intermediate Robot Language) and PLR (Programming Language for Robots) are the names of some of the established or suggested standards for neutral robot languages and robot control codes.

IRDATA has official status in Germany as a VDI (the German association of engineers) guideline for robot control code, and it will be implemented as German DIN standard in the near future. ICR can be looked upon as a successor of IRDATA. The work on ICR has mainly been undertaken by France and Germany. ICR has been proposed as an ISO standard but this was rejected by the ISO working group. PLR is a German attempt to create a higher level robot language. The term higher level reflects a Pascal-like syntax in contrast to the more assembly level which ICR and IRDATA operate with. IRL is, like PLR, a neutral robot program language with a Pascal-like syntax. IRL offers the general functionality of a high level programming language allowing interaction with external devices. Multi-robot handling, multi-tasking and support for off-line robot programming are also among the features of IRL. Portability is, of course, one of the main targets with a neutral language such as IRL. IRL has been suggested to CEN as a proposal for a European standard, (DIN 66312 1993).

The introduction of a working neutral robot programming language will have numerous effects. First, the costs of creating robot programming software will be dramatically reduced since the only difference from one vendor to another will be the man-machine interface. The resulting robot control code will be in a standard format portable to any robot which accepts standard robot control code. Post-processors from the standard control code to the proprietary control code will soon be introduced on the market. However, it is a long way from the current status of standardized neutral robot programming to a functioning industry accepted standard. Ad hoc standards or proprietary but open normal robot programming formats are probably the solution for today's demand for a neutral robot programming language.

## Open Standard Robot Macro Library

Presently, there is no international work on standardization of robot macros. The introduction of a standard open robot macro library written in a neutral robot programming language would be of great interest for the shipbuilding industry. The potential number of licenses sold would ensure that the price level of robot macros would drop dramatically. However, a number of problems must be solved. First and foremost the neutral **robot programming language must become a working** standard before the industry will risk committing itself to an open macro library.

## SUMMARY

We have presented the current level of robot technology in the shipbuilding environment}

A case study of a modern computerized and robot based web and component line is included in this text to present the "state of the art" in robotized production in the shipbuilding environment,

A survey of the most relevant technologies with respect to robot production in the shipbuilding industry is also included.

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## Shipbuilding Robotics and Economics

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### ABSTRACT

Commercial shipbuilding is surviving and prospering in mature high-labor-cost countries even under intense competition from low-labor-cost countries. Prospering shipyards are investing in robotic automation to increase productivity and worker added value. Robot welders are producing higher quality ships for as little as \$1 per hour. It is projected that U.S. shipyards must also use robots in order to successfully compete in commercial world markets. This paper describes how the Technology Reinvestment Project (TRP) **on Shipbuilding Robotics is leveraging advanced** robotic technology to provide low-cost robotics for U.S. shipyard automation. The TRP is described, economic analysis methods for robot welding are presented, and factors for Successful implementation of robotics are discussed. A case study of a successful shipyard gantry robot implementation is reported.

### INTRODUCTION

With the advances in mechanization and automation in manufacturing during the past 40 years, ship manufacturing is also becoming more mechanized. During the past decade a number of shipyards have successfully employed robot welders. Many of these shipyards are welding more than 25% of the ship with robots with goals of over 80%.

A robot welder works for between \$1 and \$5 per hour, produces predictable welds, optimizes weld consumable costs, reduces inspection and rework costs, and delivers a consistent higher quality product. The economics of robot welding

are simple and powerful. Robot welders, working for skilled shipbuilders, make ships better, cheaper, and faster than other methods.

However, present generation shipbuilding robots, known as numerical control (NC) robots, require that shipyard owners have the ability to develop software, hardware, and processes necessary to employ these robots in their shipyard environment.

Identifying a need for a better solution to shipyard automation, the Technology Reinvestment Project's 12 partners, under the leadership of CYBO Robots, are developing a low-cost robot system specifically for shipyards. The project will develop low-cost robot welders designed for the unique needs of U.S. shipyards (Office of the Press Secretary, 1993).

### Revitalizing Commercial Shipbuilding in the United States

The geopolitical changes that are reshaping the U.S. defense establishment are having a profound effect on U.S. shipyards. Fewer Navy ships will repurchased as a result of recent changes in world politics that have redirected U.S. defense spending. Projections show that under the status quo, most U.S. shipbuilders will not remain viable during the upcoming periods of low Navy procurement (MARITECH, 1994).

A viable shipbuilding infrastructure is essential to the United States; it is the primary means of building and maintaining the fleet that is the core of modern Naval defense. The only way the United States can afford to retain the shipbuilding capacity necessary for national defense is to assist U.S. shipyards to become

**commercially competitive. Otherwise, they will be** forced to close, depriving the United States of needed shipbuilding capacity for mobilization, posing a serious threat to national security, and causing even higher Navy ship costs.

This TRP plans to reduce Navy ship costs and to assist U.S. shipyards to become commercially competitive. It anticipates that successful completion of the project will assist shipyards to compete in a \$364 billion world market, increasing the number of high quality jobs in the United States, and help eliminate a national security threat created by U.S. dependence on foreign products in these critical areas (NSA-USRI, 1991) (NSI, 2) 1993).

#### Competitive Environment

The current competitive environment for world shipbuilding is composed of shipyards with a wide range of labor costs. In industrialized countries, labor costs range from about \$8 to \$23 per hour. Table I details average labor costs for European Economic Community (EEC) and other foreign yards.

Hourly Costs	Country
\$19.60	Belgium, Germany
\$19.05	Japan
\$18.00	Finland
\$17.50	France, Italy, Denmark, Spain, Netherlands
\$8.80	Greece, Portugal, United Kingdom
\$8.35	Korea

Table 1. Hourly Shipyard Costs for European Economic Community and Other Countries (CEC, 1992)<sup>1</sup>

#### WHY ROBOTICS

Much like personal computers increase the abilities of people to manipulate symbols and words in an office, robots increase the abilities of people to perform production processes. Through

<sup>1</sup>Labor costs include national social benefit costs.

robotics, the value of human labor is increased, resulting in greater economic return for business and higher wages for workers.

The U.S. is more than 15 years behind Japan and Europe in the application of robots. Japan has at least six to eight times as many robots as the United States, and Japanese companies install more robots each year than the U.S. basin total (RIA, 1993). Robot use in Japan began more than fifteen years ago when Japan began using robots to solve a shortage of skilled workers. They discovered that robots improved product quality and gave them important manufacturing advantages. They also learned that robots: 1) improve working conditions, 2) improve the quality of work, and 3) improve the standard of living for workers, solving societal problems while increasing the value of labor and **justifying higher wage rates.**

During this same period, most U.S. manufacturers had an adequate supply of skilled workers and no fundamental need to employ robots, so they didn't. Only the U.S. automotive sector, faced with a changing market situation created by the improved quality of Japanese automobiles, were forced to adopt robots to achieve the necessary quality and cost-reduction levels.

#### The Trend to Robotics

Today, the situation for most manufacturing in the United States is changing. Some industries are facing shortages of skilled workers, others have concerns about rising labor costs, and many manufacturers are encountering higher product quality levels established by overseas competitors with robots. In 1992 the U.S. robot industry experienced its first growth in almost a decade. U.S. robot consumption grew to \$590 million in 1992, up from \$415 million in 1989. Continued growth is forecast at about 11% through the end of the decade with 1994 estimated at \$750 million. (Frost & Sullivan, 1994)

In the future, demographic studies predict major shortages of skilled workers as the baby boom generation retires and the need for service workers increases. These shortages will be compounded by declining worker skills and decreasing desirability of manufacturing trades. Further compounding the situation will be the impact of increasing global competition on all

industries, where consumers demand higher quality, more selection, and faster response. All of these factors will increase the need for robots.

#### Warning Proceed with Caution

During the rush to implement robotics in the automotive industry in the 1980s, many millions of dollars were wasted by moving too fast with too little knowledge. U.S. robotics history contains numerous costly times where foreign robotic technology was seen as a means to catch up. Robotics is a complicated technology with a steep learning curve that is reduced only through knowledge and experience.

Shipyards create a new class of technical issues that must be solved to apply robots. Shipyard robots are different from industrial robots. Industrial robots are designed to work in factories where the environment is structured, organized, precise, and predictable. Industrial robots are designed to perform the same task repeatedly, many thousands of times, and programming can take from days to weeks for each part. Shipyard needs are different. Most ship components are currently manufactured with a precision unacceptable for industrial robot applications, and are produced in low volumes, making programming costs prohibitive.

In Japan, shipyards that use robots have had to develop their own proprietary NC robots and software for offline programming. They have also simplified ship designs and modified their shipyards and manufacturing processes to produce the high-precision structural components which current generation NC robots require.

## SHIPBUILDING WITH ROBOTS

### Numerical Control (NC) Robots

Japanese NC Robots. In the late 1970s, the Japanese shipbuilders began developing NC robots for shipyard welding. One shipbuilder, Hitachi Zosen, is an advanced developer of robots for shipbuilding. The National Shipbuilding Research Program SP-7 Committee sent a team to Japan in April-December 1991 to investigate this system (Blasko, 1993).

The investigating team reported that these NC robots are used primarily for straight line welds.

They are programmed offline by numerical control, similar to machine tool programming. They have touch sensing and an elementary form of arc seam tracking. Ship component accuracy control is critical to use these robots, and parts are prepared and located within  $\pm 1$  millimeter.

In early 1992, robotic welding accounted for more than 20% of this shipyard's welding with a near-term objective of 50%, and a long-term goal of 80% of all welding to be done with robots. This shipyard's philosophy combines cost reduction with elimination of difficult and dangerous work while increasing the productivity of workers. Robotics previewed as an integral part of a total manufacturing philosophy, of which the robot is but one element.

The committee's report concludes that the application of robots provides good potential to improve the competitive position of U.S. shipyards, but that selective picking and choosing individual elements of Japanese shipbuilding technology to be used in U.S. shipyards will have hidden costs because of the need to integrate that equipment with the ship design and construction process planning effort. Selecting individual elements of technology or equipment without developing an integrated system for ship design, process planning, and construction was not advised (Blasko, 1993).

NC Robots in Denmark. Odense Steel Shipyard began automating ship production in 1984 with an ESPRIT project to apply Computer **Integrated Manufacturing (CIM) to heavy welded** fabrication. In 1987, they entered into a license agreement with Hitachi and began incorporating NC robots into their automation.

Since that time they have made a sizable investment in the development of their own proprietary software and hardware to apply these NC robots in their ship production. Their robot systems, offline programming software, welding processes and manufacturing methods are now among the best in the world. They have rationalized and integrated a total shipbuilding factory and improved the efficiency of the application of NC robots. They have also developed proprietary robot handling equipment, programming tools, and process monitoring systems. By 1991 they were producing double hulled tankers with this system, and are currently

expanding and improving its performance. The economic results of an application of their gantry mounted robots are presented in this paper as a case study.

Specialized software was developed by the shipyard to automate the programming of NC robots directly from the CAD ship design data. Their software incorporates rule-based methods to create individual weld path programs from a library of weld process plans. The software also divides the welding tasks for an entire ship panel to create task plans for each welding robot (see Figure 1).

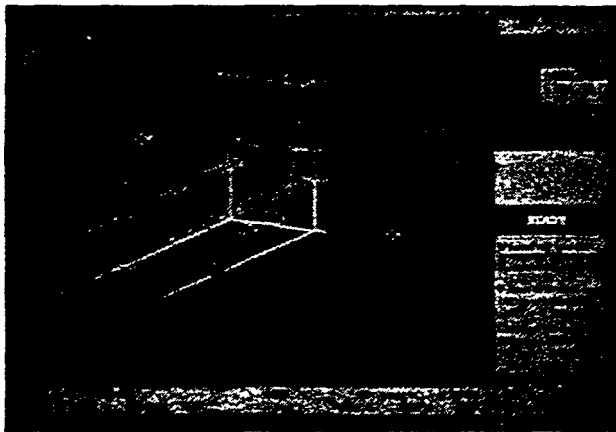


Figure 1. Software for Automatic Programming

These pioneers have demonstrated that NC robot technology can be successfully applied to shipbuilding provided that the production process, the workplace, and the materials are modified to provide a sufficiently structured and controlled environment in which an NC robot can perform its planned tasks. They have also shown that careful planning, creation of a technical development staff, involvement of all shipyard disciplines, and a total shipyard commitment are necessary ingredients for successful implementation of this technology.

#### Need for U.S. Shipyard Robot Technology

Shipyard robot technology is still in the early stages of development and requires a great deal of technical support by the owner. For example, the Danes invested in equipment and software development for more than 10 years to implement

the Japanese technology. Such custom support is difficult to import due to differences in standard practice, hardware, work methods, communications, and distances between countries. Therefore, local development and support is preferable.

The cost of procuring and implementing foreign equipment and technology is another factor cited as creating the need for a U.S. shipyard robot technology base. Japanese NC shipbuilding robots can cost between \$150,000 to \$200,000 per robot. Support equipment, facility modifications, installation, and training can more than double this cost, making the investment about \$300,000 to \$400,000 per robot. Needed specialized CAD software and robot programming software adds an additional \$1 million to \$2 million of cost. In addition, the shipyard must hire a specialized development staff to design and build the necessary custom equipment, integrate these robots, and develop the necessary support software to integrate their CAD data with the robot programming software. **The Danes, for example, maintain a staff of 20, at an estimated cost of about \$1 million per year, for development and support of their Japanese NC robots.**

For a U.S. shipyard to implement foreign shipyard robots, it is estimated that a minimum investment of between \$3 million and \$4 million is required to begin, and total investment of \$10 million to \$25 million should be expected. The TRP partners felt that most U.S. shipyards lacked the necessary capital to invest in foreign robotics in addition to the necessary investments in new ship designs (NSI, 1993).

Additional factors creating a need for a U.S. shipbuilding robot technology base were the need **for a competitive advantage in shipbuilding. If the U.S. is able to develop a technological lead in shipbuilding robotics, it can use that lead to improve its competitive position and reduce its dependence on foreign technology for national defense.**

#### TRP Program Goals

The goals defined in the TRP Shipbuilding Robotics include development of: 1) a total robotic welding system for shipbuilding 2) modular robots with advanced sensing and adaptive abilities that

can operate in unstructured environments and be reconfigured for various tasks, 3) a system with user-friendly interfaces acceptable to U.S. shipyard workers unfamiliar with robotics and automation 4) a modular networked system based on open architecture PC-based controls, 5) automatic offline programming that interfaces with various shipyard CAD/CAM design systems, and 6) low-cost support equipment to integrate and transport the robots in the shipyard environment.

The project also has long-term goals to develop 1) real-time weld process quality monitoring 2) adaptive correction of weld problems as they occur, and 3) process control which correlates and records weld quality information with ship location. The planned result will be improved weld quality and reduced cost of weld inspection which should further reduce ship production costs.

## NEW GENERATION OF ROBOTS

The planned system includes the following modular components that link together in a variety of configuration 1) modular robots, 2) open-architecture robot controllers, 3) supervisory controllers, 4) offline design and process database system, 5) low-cost part registration systems, 6) Nation low-cost robot positioning devices, 7) sensor-based adaptive process control, and 8) weld quality sensors. Each component of the system will run on low-cost PC hardware and will be linked via standard Ethernet local area networks (LAN).

To reduce costly programming the project is developing offline automatic programming software that uses CAD data to program robot paths in conjunction with knowledge-base system data for weld process and sensors. This automatic programming will work in conjunction with inputs from registration systems to accommodate rough robot positioning and with local robot sensors to adjust these programs to adaptively compensate for variations in component parts.

To ensure that the system design correctly anticipates the needs, and preferences of U.S. shipyards, three major shipyards are members of the development team: Ingalls Shipbuilding, Inc., Bath Iron Works Corporation, and National Steel and Shipbuilding Company. These shipyards are

supplying their welding and manufacturing expertise to assist in developing system specifications to monitor the program, and to test and evaluate the systems and components as they are developed.

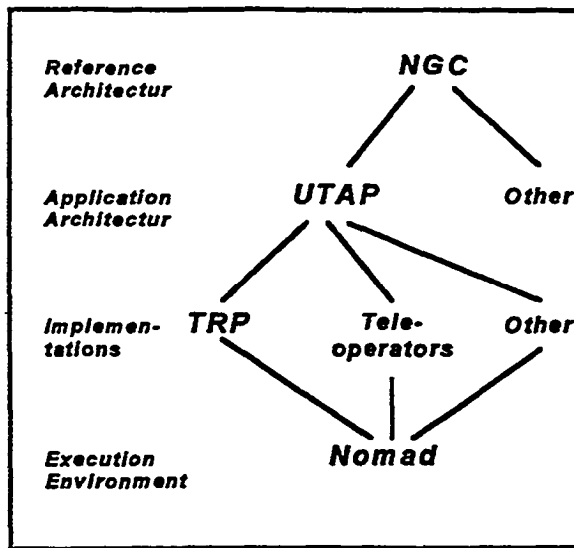
The core technology for this project already exists. The commercial, university, and government members of the team are modifying their existing software and equipment to meet the development specifications. Software is being ported to the PC environment, capabilities are being added to enable the equipment to work together, and features are being added to provide the performance and user interfaces defined by the shipyards.

The system operating architecture is being designed to comply with the Next Generation Controller (NGC) Open System Architecture Standard (SOSAS) (NCMS, 1994) and the Unified Telerobotic Architecture Project (UTAP) application architecture (Lumia, 1994). A special meeting of groups concerned with these specifications was held July 25-27 in Atlanta, Georgia, to discuss the planned system. The groups represented included the Navy, the Air Force Material Command (AFMC) Robotics and Automation Center of Excellence (RACE), National Institute of Standards and Technology (NIST), Army Tank and Automotive Command (TACOM), Department of Energy (DOE) Sandia National Laboratory and Oak Ridge National Laboratory, Next Generation Controller (NGC) National Center for Manufacturing Science (NCMS), Boeing, CYBO Robots, and Trellis Software and Controls. At that meeting it was agreed that: 1) the UTAP conforms to and is an application architecture of the NGC SOSAS; 2) the TRP is an implementation of the UTAP Application Architecture and is consistent with the NGC; and (3) Nomad<sup>TM2</sup> is a specific implementation of the UTAP Application Architecture that provides an execution environment consistent with the NGC. Figure 2 illustrates the relationships of these items (Stoddard, 1994).

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<sup>2</sup>NOMAD is an open-architecture controller product of Trellis Software & Controls, Inc.





**Figure 2. TRP Implementation of the NGC and UTAP**

**In Phase I of the program, the equipment, software, and systems are being designed, built, tested, and demonstrated. In Phase II, the systems will be installed in shipyards to validate the benefits of robotics in a production environment, refine the system software, and ensure the quality of the system implementation. Phase I is scheduled for completion in June 1996.**

#### Automatic Programming.

The offline welding simulation and database system developed under the Navy's Programmable Automated Welding System (PAWS) will be the heart of the Offline Programming System (OLP). As a part of this project PAWS is being expanded and enhanced to store Ship part descriptions, programming macros, various process strategies, and additional weld process requirements.

For most users, part data are downloaded directly from a shipyard's computer-aided design (CAD) database. For shipyards which are not CAD based, a macro description language is being added to define the basic components of ship panel assemblies and typical panel component intersections.

A process knowledge-base for ship welding is being developed to store the welding process data, weld sensor data, and robot adaptive control Strategies. These databases are linked to users at

an offline process development station through **programming tools consisting of ship section analysis macros and process fitting macros** that are being developed to simplify and accelerate the offline programming tasks.

Once the ship panel design and process knowledge have been entered into the databases, the offline system will determine which robots should be used to weld specific ship sections and where these robots should be placed to optimally weld each section. The offline system generates robot programs taking into account path trajectory, equipment, and welding factors. The offline system also generates maps of robot placement locations and identifies welds that must be manually completed during the tack welding and fitting operations.

**Robot Placement.** The plan for panel assembly is to fit and tack weld structural components in their proper locations. The robots will be placed on the panel manually or automatically. The physical map generated by the offline system guides manual robot placement. For automatic placement, the offline system electronically sends robot location information to the placement system controller.

In the case of automated gantry robot placement, the panels are assembled in one of the designated fixture zones within the gantry working area. A system operator confirms the panel part number and confirm through the supervisory controller that the panel is ready for welding. once automatic operation is initiated, the supervisory controller moves the robot gantry to the first welding location. The controller correlates part location registration data from registration sensor systems with offline weld paths to generate and download weld paths to each robot.

A similar procedure is used when robots are placed manually or by crane. In all cases, there is no need to directly program the robot either on line or offline. All programming is automatic from the information stored in the offline database.

**Robot Registration.** Robot registration is performed prior to weld start to compensate for robot placement and inaccuracies in the preparation and fit-up of the section to be welded. The robot programs contain instructions for registration of the robot position with respect to the section to be

welded. Three types of robot registration are available. One or more registration methods may be used depending upon the precision of the preparation of the sections to be welded, and the precision with which the robot is placed.

A registration system based on triangulation provides the location of the section to be welded and the robot to about  $\pm 25$  mm (1 inch). A the dimensional (3-D) sensor mounted on the robot provides registration between the robot and the section to be welded to about  $\pm 7$  mm (0.28 inch). Displacement sensing provides registration of the robot to the section to about  $\pm 1$  mm (0.04 inch).

**Adaptive Capabilities.** The robot can work in conjunction with a variety of sensors to achieve adaptive process control. Sensors include optical, touch, arc tracking and vision. Through these systems the robots are able to compensate for variations in robot and part locations and weld joint fit-up. Sensors are provided to locate the precise weld start and stop locations, to adjust process parameters including fill, weave, and position based on fit-up variations, and monitor and control the position of the welding arc with respect to the weld joint center location.

**Weld Quality Monitoring.** A weld quality monitor will be available for each robot. The sensor collects and analyzes data gathered during welding to determine that weld quality is maintained within established limits. If the welding wire runs out, or welding problems develop due to faulty wire feeding equipment or inadequate weld gas coverage, the affected robot stops and alerts the system operator. The operator can then make corrections and instruct the system to resume from where it stopped.

Upon completion of each weld segment, a weld record database for that section will be updated to record the welds completed, the weld cycle time, and the monitored process quality data. This information can be used for statistical process control (SPC) to determine where manual welders must complete unfinished welds, and to direct weld inspection and repair.

**User Friendliness.** The functional specifications for the system have been created by surveying the participating shipyards to determine their manufacturing practice and methods. User-friendly interfaces and methods that mirror

common U.S. shipyard practice are designed into the system to tie together the existing shipyard infrastructure in a manner acceptable to shipyard workers, technicians, engineers, and managers.

**Maintenance.** Maintenance costs for the system will be low. The use of open-architecture, PC-based controllers will greatly reduce maintenance costs. Components are available from a wide range of sources, and the popularity of PC hardware ensures availability of a large body of trained technicians to support the equipment.

## ROBOT ECONOMICS

Traditional U.S. financial analysis practice uses different methods to evaluate capital investments depending upon the nature of the investment. For example, an investment in a facility is evaluated over the expected useful life of the facility, including equipment in the case of dedicated facilities like steel mills and chemical plants. A useful life of 30 years might be used for such evaluations. Investment in manufacturing equipment is usually evaluated over shorter periods because equipment is often superseded by new and more efficient models. A useful life of 3 to 5 years is commonly used to evaluate such equipment, with many companies seeking payback of investment in 1 to 3 years. Investment in labor is rarely evaluated. Labor is usually treated as available "on demand," that is, it can be obtained or discharged at will.

A lack of a historical financial analysis practice for robots creates a dilemma for performing robot economic evaluations, whether they should be considered facility, equipment, or labor. Arguments can be made to support each method, as robots have characteristics of all three. Like a facility, robots can be a part of the basic structure of a manufacturing business, are universal, can be applied to many tasks, and can be used by different owners. Like equipment, a robot can be used for specific tasks, but unlike equipment can be upgraded with new processes when they are available. Are robots more like repurchased labor? Like labor robots can be used for many tasks, moved to many locations, and can be taught and re-taught various skills and duties, and if in excess, can be sold.

If a **business** considers robots as integral to the manufacturing process and evaluates robots as a part of a facility investment, the financial analysis will focus on long-term objectives.

If robots are treated as equipment, they must compete against specialized machines that typically are expected to provide quick returns on investment. Such specialized machines generally have limited versatility and can be quickly made obsolete by a change in process or design. Equipment owners generally seek rapid payback of their investment to ensure that prompt equipment replacement can be justified if required to remain competitive. Such an analysis method may eliminate robot solutions and sacrifice long-term strategic advantages for short-term returns.

Robots may be more appropriately considered direct labor replacements. However, at present, the methods for evaluating labor are not investment-based. Typically labor is treated as a service that is purchased at-will and measured on an hourly or annual cost basis. Often only direct labor compensation is considered, without calculating the total social costs, and rarely, if ever, are the projected length of employment and termination costs computed and included in labor cost. Therefore, if robots are to be evaluated as labor alternatives, a new method is needed.

An argument can be made for developing this method as follows. Current manufacturing practice usually relies on a significant amount of skilled and semi-skilled labor. The total amount of labor to be performed is usually known and costs are typically assigned to the labor content. These costs are often based on an hourly labor rate. If one considers the life span of the business as the basis for needing labor, a robot can be reconsidered as an alternative to at-will labor employment. The business can then evaluate the financial impact of a strategic decision to use robot labor versus at-will labor. Following is a quick method to compare robot to labor using hourly costs.

#### Hourly Robot Cost

The evaluation of robots on an hourly labor cost basis describes the cost savings benefit in terms that permit comparison to manual labor. To compare robots to manual labor, one must first describe their relative efficiencies.

#### Robot Efficiency

Typically, a manual welder's efficiency is estimated between 15% and 40% arc time depending upon the process and the welding position. The national average arc time is estimated at about 30%, but this figure may be high (Pavone, 1983).

A robot will typically average 60% to 90% arc time depending on the type of work (Pavone, 1983). If we assume the average robot will achieve the average of this range, the robot will have a 75% arc time.

$$(60\% + 90\%)/2 = 75\% \quad (1)$$

Compared to the manual welder's average arc time of 30%, the efficiency of the robot is 2.5 times (2.5x) that of the manual welder.

$$75\% / 30\% = 2.5x \quad (2)$$

In most shipyard applications, the robot cannot work alone. The robot must be serviced by an operator. One operator can keep between 1 and 4 robots supplied with work, for an average of 2.5 robots.

$$4 \text{ robots} / 1 \text{ operator} = 2.5 \text{ robots per operator} \quad (3)$$

Therefore, one operator divided among 2.5 robots consumes 0.4 times relative efficiency.

$$1 \text{ operator} / 2.5 \text{ robots} = 0.4x \quad (4)$$

Therefore, for shipyard applications, one can adjust the relative efficiency calculated above by this factor. Hence:

$$2.5x - 0.4x = 2.1x \quad (5)$$

Figure 3 illustrates how a robot operating at this efficiency can provide output of 2.1 to 6.3 manual welders depending on the number of shifts the robot is employed.

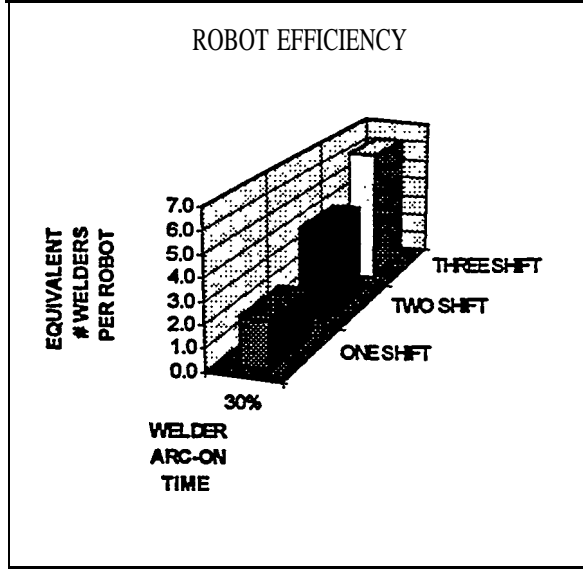


Figure 3. Robot Efficiency

**Process Efficiency.** Another potential robot efficiency factor is process efficiency. In arc welding a robot can deliver higher deposition rates than manual welders due to its ability to hold a steady arc under the severe environmental conditions of heat, smoke, and light generated by the process. Robot weld deposition rates can range from 20% to 100% higher than manual rates. This provides a direct increase for robot efficiency of 0.2x to 2x.

$$(100\% + 20\%) / 100\% = 0.2x \quad (6)$$

and

$$(100\% + 100\%) / 100\% = 2x \quad (7)$$

Actual process efficiency improvements for shipyard robot welding have not been reported. If we assume them to be about 20%, we can use the efficiency factor of 0.2x (see Equation 6).

Therefore the estimated shipyard robot efficiency factor will be 2.3x.

$$2.1x + 0.2x = 2.3x \text{ (shipyard efficiency)} \quad (8)$$

**Robot Hourly Cost.** An hourly robot cost can be calculated that describes the cost of the

robot directly compared to the manual labor alternative. This robot cost on a per-hour labor basis can be calculated as follows:

$$(C_R (1 + M_R) + P_R) / (L_R \times E_R) = RC \quad (9)$$

where:

$C_R$  = Initial robot cost (\$)

$P_R$  = Expected programming cost (\$)

$M_R$  = Expected maintenance over robot life in percent of initial cost (%)

$L_R$  = Expected robot life (hours)

$E_R$  = Estimated robot efficiency factor (%)

$RC$  = Robot hourly cost (\$)

Initial robot cost typically varies from \$50,000 to \$200,000 depending upon the manufacturer, size, and features. The new generation robots are projected to cost less than \$50,000, while Japanese NC robots cost between \$150,000 to \$200,000 each.

Programming costs vary widely depending upon the specific robot application. For example, in a high-volume production situation where the same tasks is performed throughout the life of the robot, programming costs might be a few thousand dollars. In a shipyard production situation, where the robot is frequently programmed, the **programming costs might range from \$200,000 for teach programming, to as little as \$10,000 for automatic programming, depending upon the number of programs required and the efficiency of the programming method.**

The programming costs for the new generation robots can be calculated by dividing the estimated initial software and hardware costs plus the 5-year software operation costs by the number of robots to be programmed and the 5-year estimated robot life as follows:

$$(\$100,000 \text{ initial cost} + (5 \times \$50,000 \text{ operating costs})) / (25 \text{ robots}) = \$14,000/\text{robot} \quad (10)$$

The programming costs for Japanese NC robots can be calculated similarly:

$$(\$1,000,000 \text{ initial cost} + (5 \times \$50,000 \text{ operating costs})) / (25 \text{ robots}) = \$50,000/\text{robot} \quad (11)$$

Maintenance costs can be expected to be about 50% of the initial cost of the robot, depending upon the robot manufacturer's design, the application, the operating environment, and the maintenance provided.

Robot life is typically 3 shifts per day for 5 years, or about 30,000 hours, without major overhaul depending upon the environment, application, and maintenance.

Robot efficiency factors have been described previously. Therefore, for a new generation shipyard robot the hourly robot cost can be Calculated as:

$$(\$50,000 (1 + 0.5) + \$14,000) / (30,000 \text{ hrs.} \times 2.3) = \$1.29 / \text{hour} \quad (12)$$

For Japanese NC robots for shipbuilding the hourly costs for these robots would be:

$$(\$150,000 (1 + 0.5) + \$50,000) / (30,000 \times 2.3) = \$3.98 \text{ per hour} \quad (13)$$

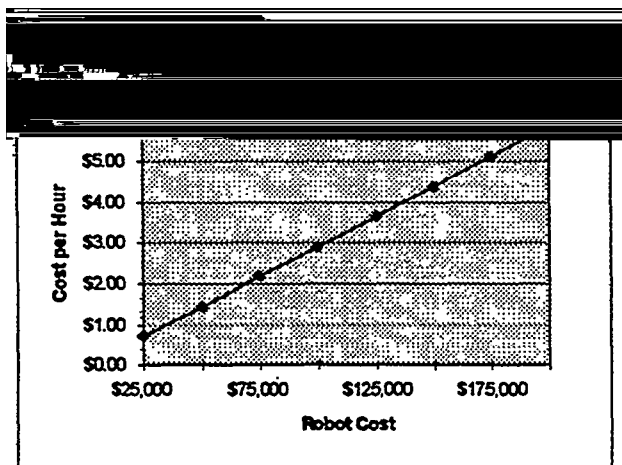
and,

$$(\$200,000 (1 + 0.5) + \$50,000) / (30,000 \times 2.3) = \$5.07 \text{ per hour} \quad (14)$$

respectively.

By this method, it can be calculated that, over a large range of initial robot costs, assuming a 50% cost for lifetime maintenance. and a 25% cost for

between \$0.73 and \$5.83 per hour as shown in Figure 4.



**Figure 4. Robot Cost per Hour**

### Period Cost Savings Method

To extend the output of the above hourly cost method to calculate period cost savings the following steps can be taken.

$$LC - RC = S \quad (15)$$

and,

$$\text{number of robots} \times Sh \times Y \times H = \text{Total Savings} \quad (16)$$

where:

S = Savings (\$)

RC = Robot hourly cost (\$)

LC = Labor hourly cost (\$/hr)

Y = Years

Sh = Shifts

H = Hours worked per shift-year

For example, if a shipyard with a \$20 per hour labor rate evaluates producing 3 shifts per day with 50 robots for the next 5 years, the following savings can be calculated for the \$50,000 robots:

$$\$20.00 - \$1.26 = \$18.71 \text{ per hour} \quad (17)$$

yielding:

$$50 \times \$18.71 \times 3 \times 5 \times 1920 = \$26,942,400 \quad (18)$$

in total savings.

For the \$150,000 robots:

$$\$20.00 - \$3.98 = \$16.02 \text{ per hour} \quad (19)$$

yielding:

$$50 \times \$16.02 \times 3 \times 5 \times 1920 = \$23,068,800 \quad (20)$$

in total savings.

Direct costs savings of this magnitude are significant. It is estimated that robotic welding will yield additional savings in inspection, rework, and consumables that will more than equal these direct labor costs. If this is true, savings of over \$50 million could be anticipated in the above example.

### Additional Factors

In the preceding calculations a manual welder efficiency of 30% arc time was assumed. This arc time is very aggressive, with some shipyards

reporting actual arc times between 15% and 20%. If the actual shipyard manual welding efficiency is different than the 30% used, the results of the calculations will differ significantly. Figure 5 shows how variations in manual welder are-on time impact the relative calculations of robot savings.

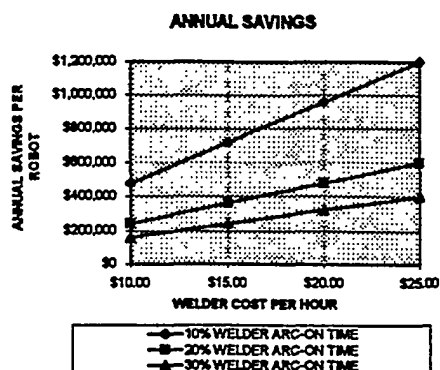


Figure 5 Annual Savings

## CASE STUDY - GANTRY ROBOTS

A Danish shipyard produces various types of vessels, ranging from supply vessels to super tankers in the Very Large Crude Carrier (VLCC) Class (Skjolstrup, February 1994). Throughput is important to this yard's operation; each production department completes its work on a ship in 60 days, and a ship leaves the shipyard in 10 months. Robot welders produce consistent high quality welds as pictured in Figure 6.



Figure 6. Close-Up of Robot Weld

The yard currently has 26 robots in production that are used in both block assembly and in sub-element fabrication for blocks. Four methods move and position robots for welding double hulled tankers: 1) manual relocation 2) gantry positioning 3) master-slave gantry positioning and 4) telescoping boom system for double hulled tankers. The manual relocation robots are pictured in Figure 7.

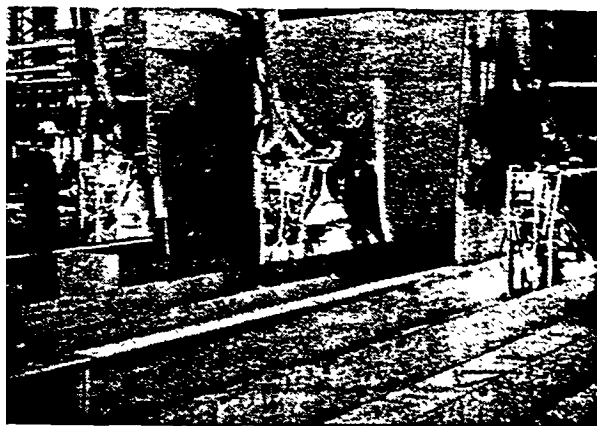


Figure 7. Manual Relocation Robots

**Gantry Robot Application.** In the gantry robot application pictured in Figure 8, there are four independent gantries mounted on one rail system. **Each gantry has three servo-controlled axes to position the robots over the sub-elements to be welded.** The track is 68 meters long and up to two gantry robots can work on the same sub-element at the same time. The shipyard reports that the one robot-per-gantry system is very flexible and it is easy for one operator to handle multiple gantries. The objective of this analysis is to compare robot efficiency with manual welding efficiency.

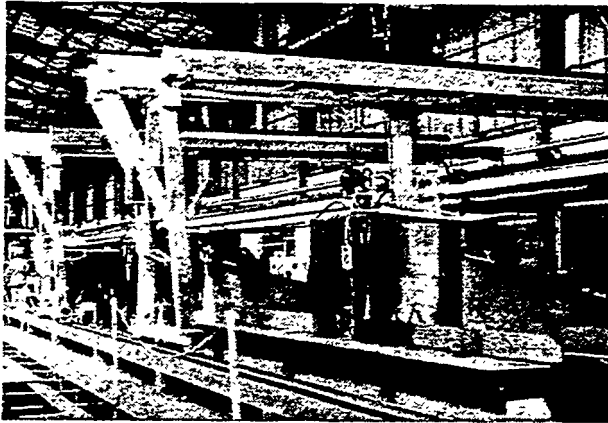


Figure 8 Two Gantry Robots

Manual welding speed and robot welding speed differ due to the more efficient process delivery capabilities of the robot. Table II lists average welding speeds for both types of welding.

Weld Position	Manual Welder	Robot Welder
Vertical up	100 mm/ min	150 mm/ min
Downhand	250 mm/ min	400 mm/ min

Table II Welding Speed

**Manual Welding Efficiency.** Manual welders range between 10% and 40% arc time. Typically they average between 20% to 30% arc time. The work day consists of 14.4 productive hours on two shifts. Of this, 1.4 hours are used in repair, netting 13 hours of welding each day, or 6.5 hours per shift per welder. For ship sub-elements, 20% of the welding is vertical up and 80% is downhand, yielding an average manual weld speed of 220 mm/minute. Therefore, a person with an arc time between 20% and 30% produces between 16 and 24 m/day of weld.

**Gantry Robot Welding Efficiency.** The gantry robot department produces about 370 sub-elements per ship. With 233 work days available per year and 60 days per ship, this yields 1440 total sub-elements per year. The average weld length per sub-element is about 100 meters; therefore, the average weld length produced per day is:

$$(1440 \text{ subs} \times 100 \text{ m weld/ sub}) / 233 \text{ days} = 618 \text{ m/day} \quad (17)$$

As there are four robots, this yields:

$$618 \text{ m/day} / 4 \text{ robots} = \sim 155 \text{ m/robot/day} \quad (18)$$

which is equivalent to between 6 and 9 manual welders per robot.

**Future Efficiency Improvements.** The factors that affect system efficiency are robot availability, material availability, and data availability. One way to measure total system performance is to calculate arc-on time. For this gantry system the average weld speed for robot welding of sub-elements is 350 mm/min. Therefore the average arc-on time for each robot is:

$$(155 \text{ m} / 350 \text{ mm/min}) / (14.4 \text{ hours/day}^3 \times 60 \text{ min/hr}) = 52\% \text{ arc time.}$$

Due to work schedule rules (required breaks) for this facility, this calculated arc time must be **adjusted to obtain true arc time. The adjustment factor is 0.8**, therefore the effective arc time is:

$$52\% / 0.8 = 65\% \text{ arc time}$$

**The current goal is to increase effective** arc time to 75%, and the shipyard automation team believes that 82% arc time is possible. When this level of efficiency is achieved, the robots will be producing at the equivalent rate of 5 to 7.5 manual welders per shift.

To achieve these levels, improvements in operator efficiency and machine availability must be made. The 65% arc time represents 75% of the actual run time. The remaining 25% is used for robot positioning, sensing, calibration, and safety. For this system the gantry run time is 87% of the total time, with 13% of the time used for consumables, handling, and set-up. This can be expressed as follows:

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<sup>3</sup>This particular shipyard's work rules create a situation where the robots work 14.4 hours per day. Robot, in general, are capable of working 24 hours per day.

$$\text{Arc Time \%} = \text{Operator Efficiency} \times \text{Machine Availability} \times \text{Process Efficiency} \quad (19)$$

Currently the shipyard is achieving:

$$52\% = 80\% \times 87\% \times 75\% \quad (20)$$

In the near term the goal is to improve operator efficiency to 90%, and machine availability to 97% such that

$$75\% = 90\% \times 97\% \times 85\% \quad (21)$$

The long-term goal is to improve operator efficiency to 100% which will result in an arc time of 820%:

$$82\% = 100\% \times 97\% \times 85\% \quad (22)$$

**Weld Wire Deposition Rates.** In terms of weld wire deposited the following estimates were reported:

Source	Kg of Weld wire deposited
Odense Shipyard - '93	4,200 Kg/ robot/ yr
Best Japanese shipyard - '93	3,300 Kg/ robot/ yr
Other Japanese shipyards	2,500 Kg/ robot/ yr
Odense target	15,000 Kg/ robot/ yr
Japanese target	10,000 Kg/robot/yr

Table III Deposition Rates

**Conclusions.** Gantry robots in production for more than a year have demonstrated sustained production efficiencies as forecast. It is further believed that these efficiencies can be significantly increased by improvements in system operation elements increase the available arc time of the robots.

## CONCLUSIONS

Automation is a process, not an event. It consists of many individual steps that are performed and improved over time to achieve

improved quality and efficiency. The following guidelines are offered to assist those considering investment in automation.

**Design for Automation.** Automation is a total manufacturing philosophy. It begins with ship design, incorporates manufacturing methods, and (20) requires total involvement of material procurement and preparation. Therefore, as new ships are designed, robotic automation should be an integral ingredient of the design process. Today, however, most ship designers have little or no experience with robots. Shipyards embarking on an automation path must look to robot suppliers and others for assistance during the design process.

**Part Precision Requirements.** NC shipbuilding robot technology requires that robots be presented to a workpiece in a precise and controlled manner, and that the workpiece be precisely prepared for the robot. Typical part preparation precision tolerances for NC robot welding are +/- 1 to 3 mm. (0.04 to 0.12 in.). The new generation shipyard robots under development will be capable of compensating for variations in part location of +/- 150 mm (6 inches), and detecting variations in part fit-up of +/-5 to 6 mm (0.2 to 0.24 in.), with real-time weld compensation depending upon the process, material thickness, joint type, and defect type.

Precision preparation of ship components requires investment in equipment and methods. Shipyards using NC robot technology must purchase part preparation equipment capable of **preparing parts to at least +/- 1 to 2 mm (0.04 to 0.08 in.)**. The new generation shipyard robots will be able to compensate for larger part variations, but better precision is recommended as it will yield higher productivity and quality.

**Operating Requirements.** NC shipbuilding robots operate in enclosed factories. They are not capable of outdoor production and operation in damp or high dew point environments. The new generation robots will be capable of working outdoors in damp environment.

**Worker Skills.** NC shipbuilding robots require a staff of highly skilled technicians to install, operate, and maintain the robots and systems. Lower skilled workers can be used to tend the robots, but skilled welders will be needed to make weld repairs. The new generation robots will



require less supervision and will make higher quality welds requiring fewer repairs, thus reducing the number of skilled and semi-skilled workers.

#### ACKNOWLEDGMENTS

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Appreciation and gratitude are extended to Odense Steel Shipyard Ltd. for their assistance and **cooperation.**

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# Naval Shipyard Base Realignment and Closure: The Environmental Remediation Effort

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## ABSTRACT

Mare Island Naval Shipyard was placed on the "Fast Track" toward military base closure as of October 1993. All ship projects will end by April 1995. The base will close in April 1996.

This paper discusses (1) the cooperative efforts of the federal, state and local authorities, and the shipyard, to quickly turnover the yard for effective civilian reuse; and (2) the shipyard effort to train and utilize the existing workforce as a major element in the environmental remediation effort--to both prepare the facility for reuse and to prepare the workforce for reemployment

## BACKGROUND

The shipyard is located 25 nautical miles northeast of the City of San Francisco in the North Bay subregion of the San Francisco Bay Area. Established in 1854, it is a designated National Historic Landmark. The shipyard's recent mission has been as a major repair and overhaul yard. It was included in the latest round of base closures due to Department of Defense (DoD) downsizing.

When closed a workforce of 9,000 civilians would lose their shipyard jobs. The City of Vallejo, California - the shipyard's entire 5,500 acres lie within the incorporated limits of Vallejo - would lose a major economic driving force. The Navy has estimated the environmental cleanup costs alone to exceed \$430 million.

## NOMENCLATURE/ACRONYMS

BCP	BRAC Cleanup Plan
BEC	Base Environmental Coordinator
BRAC	Base Realignment and Closure
CEQA	California Environmental Quality Act
CLEAN	Comprehensive Long-Term Environmental Action Navy
EBS	Environmental Baseline Survey

DoD	Department of Defense
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
LAN	Local Area Network
NEPA	National Environmental Policy Act
OEA	Office of Economic Adjustment
	U.S. Department of Defense
OHP	Office of Historic Preservation
PCB	Polychlorinated Biphenyl
PETE	Partnership for Environmental Technology Education
<b>RAB</b>	Restoration Advisory Board
UCD	University of California at Davis
UST	Underground Storage Tank
UXO	Unexploded Ordnance
VOC	Volatile Organic Compound
WESTDIV	Western Division, Naval Facilities Command

## PRESIDENT CLINTON'S FIVE-PART COMMUNITY REINVESTMENT PROGRAM

In an effort to promote a smooth transition from military to non-military utilization of closing military bases and facilities, and to lessen the negative impact on communities located near closing facilities, the Federal administration has developed a plan of action called the "President's Five-Part Community Reinvestment Program".

The components of this program include:

1. Base Transition Coordinators,
2. Larger Economic Adjustment Planning Grants,
3. Easy Access to Transition and Redevelopment Help,
4. Job Centered Property Disposal, and
5. Fast-Track Cleanup.

Each of these elements is being implemented at the shipyard as an integral part of the facility's overall cleanup, closure and reuse strategy. A more detailed explanation of the implementation of the Five-Part Program follows.

### **Base Transition Coordinator.**

At the center of the Five-Part Program is the Base Transition Coordinator. It is the Coordinator's job to:

1. assist the community and installation in quickly reinvesting base closure properties into other uses,
2. cut through red tape to facilitate rapid redevelopment and creation of new jobs, and
3. remove impediments to facilitate a smooth transition to economic development and reinvestment.

### **Larger Economic Adjustment Planning Grants.**

In an effort to "jump-start" the process, the Federal Government has implemented a seven-day turnover policy for approving grants to communities affected by base closures. The amounts awarded for planning grants have been increased in size allowing an average of \$1.0 million per community, with the community's total awarded over a five-year period.

The City of Vallejo has successfully pursued several State and Federal grants, including Office of Economic Adjustment (OEA) grants of \$618,000 in 1993 and \$680,000 in 1994.

### **Easy Access To Transition and Redevelopment. Help.**

The emphasis for this component of the Five-Part Program is on pooling Federal resources to give affected communities easier access to Federal assistance with a positive "can-do" attitude among Federal agencies. The cooperative effort between the City of Vallejo and the shipyard to develop a local community Reuse Plan for the closing of the Naval Base is typical of this cooperative redevelopment effort. The Reuse Plan, completed in July 1994, will be incorporated into a combined Environmental Impact Statement (EIS) developed under Federal guidelines and Environmental Impact Report (EIR), under State guidelines, to facilitate turnover and reuse of the military facility by the civilian community. The level of cooperation exhibited by this transition effort between local and Federal agencies will serve as a model for future actions of a similar nature.

### **Job Centered Property Disposal.**

Under this component of the program, low or no cost transfers have been authorized from Federal to local community ownership in an effort to encourage local economic and job development. To promote this end, interim leasing of Federally owned property is

encouraged during the closure process. This leasing program will allow local communities to utilize property sources prior to actual base closure to increase the job base and provide for economic growth. Examples include the leasing of properties such as office buildings, educational and training facilities, and recreational facilities.

Cooperative efforts to turn a potential economic disaster into an asset for the community have included

1. early invitation for community involvement in the shipyard reuse screening process,
2. shipyard support of the City of Vallejo's Mare Island Futures Project to develop and implement an expeditious reuse process,
3. shipyard and community research to identify historically significant naval base properties in compliance with the National Historical Preservation Act, and
4. political and legislative support at the Federal, State and local levels.

### **Fast-Track Cleanup.**

One of the most crucial elements in the transition process is the quick and effective environmental cleanup of closing facilities. The importance of ensuring the protection of human health, and the return of the natural environment to its pristine (as allowed by state-of-the-art technology) condition, cannot be overstated.

The mandate of the Fast-Track Cleanup process is expanded below.

Make clean parcels available for reuse. Through implementation of remediation and cleanup efforts, closing facilities are under direction to make lands designated for turnover to local communities safe to human health and the natural environment. Efforts to achieve these goals are underway under the direction of the Base Environmental Coordinator (BEC).

Speed the National Environmental Policy Act (NEPA) process. NEPA is the basic national charter for protection of the environment. It establishes policy, sets goals, and provides means for carrying out policy. Under Federal law, NEPA provides guidelines for the development of an Environmental Impact Statement (EIS). The primary purpose of the EIS is to serve as an action-forcing device to insure that the policies and goals defined in NEPA are infused into the ongoing programs and actions of the Federal Government. The EIS provides full and fair discussion of significant environmental impacts and informs decision makers and the public of the reasonable alternatives which would avoid or minimize environmentally related adverse impacts, or enhance the quality of the human

environment The NEPA evaluation for base closure and reuse must be completed within 12 months of receipt of the community reuse plan. Portions of the EIS are currently being written by the shipyard's Base Realignment and Closure (BRAC) Environmental Technical Division.

Establish cleanup teams at every base. The shipyard's Base Cleanup Team consists of the BEC, a representative of the U.S. Environmental Protection Agency (EPA), and a representative of the California Department of Toxic Substance Control (DTSC).

To increase public participation in its cleanup programs, DoD policy calls for Restoration Advisory Boards (RABS) to be formed at closing installations. The shipyard RAB includes the Base Cleanup Team members and 21 additional participants from the shipyard, the regulatory community, the City of Vallejo, and local citizens. The RAB holds frequent public meetings to increase community understanding and support for cleanup efforts, to comment on the soundness of government decisions, and to ensure cleanups are responsive to community needs.

#### BRAC ENVIRONMENTAL TECHNICAL DIVISION

The Base Environmental Coordinator (BEC) has responsibility for oversight and implementation of a large portion of the environmental cleanup at the shipyard. The BRAC Environmental Technical Division was formed to assist the BEC, and to provide environmental management "on-the-job-training" for shipyard workers displaced from their regular assignments. The new division performs work projects under contact with the Western Division (WESTDIV), Naval Facilities Command. WESTDIV is the agency responsible for administering environmental cleanup programs for the Navy in the geographical area that includes the shipyard.

A brief historical overview of the events leading to the formulation of BRAC Environmental Technical Division follows.

**Workforce Analysis.** When the decision to close the shipyard became law, one important action facing base officials was the development of an aggressive and effective outplacement program. Data was collected from employees with respect to eligibility for retirement, employment history, and future career desires. Further data was collected on what employment opportunities existed in government and private industry and what state and Federal programs were candidates for providing training opportunities to facilitate the transition of shipyard employees to private sector employment

This investigation identified that 80 percent of Mare Island's work force would be eligible for an immediate annuity if the closure process were to extend through 1999 rather than the 1996 deadline established for yard closure by the Navy. It concluded that several hundred employees would the involuntary separation upon closure unless work could be found requiring their services through 1999. Studies indicated that outplacement efforts could place essentially all these employees by 1999, or at least enable the majority of remaining employees to be eligible for an immediate annuity.

An analysis of scheduled ship repair and base closure work showed that most of the available work force could remain employed through April, 1996, the operational closure date for the base.

With this knowledge in hand, shipyard management looked for potential work assignments that would fill the employment needs of several hundred employees beyond April, 1996. The field of environmental cleanup was identified as a potential source of employment for both white-collar and blue-collar workers.

At that time, the perception of managers and regulators associated with environmental remediation was that the shipyard work force possessed excellent ship repair skills, but that these skills were not transferable to the field of environmental remediation.

In some ways, this perception was accurate. In other ways, it was not. Shipyard workers lacked training and experience in environmental disciplines, but possessed the ability to be retrained for successful transition to the field of environmental remediation.

**Training.** The University of California, Davis (UCD) was approached and readily accepted the challenge to provide timely and specific environmental training for the shipyard workforce. UCD is currently the accepted leader in the field of Environmental Engineering Education in the California university system. A partnership was formed between UCD and Mare Island. Through arrangements with UCD, and UCD Extension (a separate department in the university), on-site environmental training was brought to the yard.

A compressed schedule of environmental courses (taught 8:00 am to 5:00 pm Monday through Friday) was developed for the yard's ship-system engineers, in addition to continuing after-hours courses. The course curriculum was selected for engineers with a Bachelor of Science degree from an accredited school of engineering. The courses selected by UCD were from the standard UCD Civil and Environmental Engineering curriculum, and were presented by UCD faculty on base, or through video tapes under the

guidance of a doctoral candidate teaching assistant. Engineers entering the program had an average of ten years of experience working in their respective fields.

Engineering students in this program were evaluated by the same academic standards as on-campus students, performed similar homework assignments, and were required to pass the same written examinations as engineering students attending on-campus classes. Upon completion of this compressed schedule (Session "A" began on 5 January 1994 and concluded on 25 March 1994), and after completing an additional nine units, students would earn a "Certificate of Environmental Engineering", an industry recognized certificate issued by UCD. An option also exists for students in this program to continue to completion of a Masters Degree in Environmental Engineering.

Management subsequently focused on the non-engineer work force. The California Post-Secondary Educational System readily joined the training effort by implementing a nationally recognized training course in Environmental Technology endorsed by the U.S. Department of Energy and the U.S. Environmental Protection Agency.

The Partnership for Environmental Technology Education (PETE) program was implemented through the community college system. This program was specifically designed to provide environmental training to technicians working in the field and consists of six core courses leading to either an Environmental Technology certificate or Associate of Science degree. Students completing the AS degree have the option of continuing at State University to complete a four-year Bachelor of Science degree in Environmental Applied Engineering.

During the initial stages of this program, technicians and production employees will be trained in small groups, with each group attending different courses. Work groups will be established to take advantage of the collective knowledge of these employees. Environmental Technology Training Certificates will be completed by these employees upon completion of the after-hours training program.

Special training has been offered in Occupational Safety and Health, asbestos, lead, field sampling, and trenching. Land survey teams have been trained in preparation for large-scale ordnance surveys and plotting of magnetic anomalies.

The shipyard contracted the Idaho National Engineering Laboratory to deliver presentations on technical and project management for engineers working in the Installation Restoration Program. Follow-up visits will enhance an on-going information exchange.

**Capabilities.** The successes of the University of California and the California Community College System environmental training programs, and the achievements of the shipyard employees participating in these programs, were related to the Commanding Officer of WESTDIV and his staff. In light of Mare Island's newly demonstrated capabilities in the field of environmental engineering and remediation, it became clear that shipyard employees could be considered as a viable alternative for executing base closure cleanup activities.

WESTDIV made the decision to consider the shipyard as the contractor of choice for the expanded environmental work related to shipyard closure. WESTDIV was already working with an area-wide Comprehensive Long-Term Environmental Action Navy (CLEAN) contractor, but the additional work and accelerated schedules related to shipyard closure were beyond the capacity of that contract. Shipyard employees could accomplish closure projects and could work in partnership with the CLEAN contractor at on-going remediation sites. Proposals were requested for accomplishing environmental engineering and field work. In response to this newly appointed responsibility, the shipyard formed the BRAC Environmental Technical Division, currently working under contract with WESTDIV.

BRAC Environmental Technical Division has successfully completed several projects, with several more under way and in the preparation phase. Approximately 60 engineers have completed the basic classes and are continuing their education through UCD. Field technician training has begun. The after-hours environmental training programs have maintained steady participation.

## ACCOMPLISHMENTS

The following is a brief summary of results of the yard's environmental efforts.

### Cooperation Among Agencies.

The "fast-track" policy of the President's Five-Part Plan has implemented a level of cooperation between Federal, state, and local agencies and officials that can serve as a model for future such projects. Comprehensive training programs have been organized and implemented in weeks instead of months as a result of cooperation and fast-tracking efforts of the University of California, the California Community College System and the shipyard. Contract agreements have been reached between Western Division, Naval Facilities Engineering Command and

the shipyard in a relatively short time. Representatives from WESTDIV, U.S. Environmental Protection Agency, California Environmental Protection Agency, the Restoration Advisory Board, and the BRAC Environmental Technical Division are currently working out of the same office, providing immediate access to specialized expertise, the ability to identify common concerns and objectives, and the immediate resolution of problems and conflicts.

As a result of this increased level of cooperation between agencies, there have been successes in the effort to streamline paperwork. Emphasis is on producing concise and factual documents that meet both technical requirements, and are easily understood by all involved agencies. Guidelines for document preparation provide that 1) unnecessary embellishment and verbiage are to be eliminated; 2) documents are to reflect agreed upon understandings, thereby eliminating surprises to cooperating agencies; and 2) documents should reflect openness, timeliness, accuracy, and completeness. As a result of these methods, a typical Approval Memo was reduced from fifteen to two pages. A Health and Safety Plan was issued as an addendum of an existing document, thereby saving approximately \$20,000 that might have been spent developing an entirely new document.

#### Environmental Baseline Survey and BRAC Cleanup Plan.

BRAC Environmental Technical Division was contracted by WESTDIV to complete an Environmental Baseline Survey (EBS). The EBS is a basewide assessment and summary of the environmental condition of all properties, and identification of those properties available for immediate transfer. The EBS identifies all known and suspected areas where hazardous materials and/or petroleum products have been handled, stored, disposed of, or released within the boundaries of the shipyard and adjacent areas. When the EBS was issued and the success of that project was evident, WESTDIV representatives approached BRAC Environmental Technical Division with a request to prepare the BRAC cleanup Plan (BCP) - a plan and schedule for remediation - for the closing facility. BRAC Environmental Technical Division accepted this mandate and completed the BCP on schedule and within budget in March 1994.

#### Underground Storage Tank Project.

The BRAC Environmental underground storage tank (UST) project is tasked to find and identify

shipyard UST's (most of which have contained hazardous materials), to remove leaking or abandoned tanks from their existing locations, and to remediate the surrounding environments. All in-service UST's will be reviewed for current regulatory compliance prior to base turnover. The engineers and technicians working on this project have gained valuable skills associated with remediation and removal of UST's, and have become knowledgeable in Federal, state and local laws and regulations associated with UST's.

The field of UST removal and remediation is a very specialized area of environmental engineering, and of great value in today's environmental job market. Working under Federal, state, and local laws and regulations has prepared these employees for employment in a field that is drawing a great deal of interest at these levels.

#### Soil Remediation Project.

Soil remediation has provided a fertile ground for agency cooperation and the development of new technologies for environmental remediation and cleanup. The project manager for this project is currently working closely with UC Davis in an effort to develop new and innovative technologies to be used in a soil remediation pilot project, as well as in full scale studies. Some examples of new technologies being discussed include Enhanced Vapor Extraction, Volatile Organic Compound (VOC) Control Systems, Biofilters, and Electronic Beam Hazardous Waste Treatment Systems. The project goal is to establish an on-site soil treatment facility under the Corrective Action Management Unit concept allowed by the Resource Conservation and Recovery Act regulations. The facility would operate throughout the entire shipyard long-term remediation and would have the capability to treat soils for chlorinated hydrocarbons, heavy metals, and petroleum products, as well as other contamination on the island.

#### Site Remediation Projects.

The BRAC Environmental Technical Division currently has numerous site remediation projects in various stages of completion. This work includes removal of soils contaminated with fuel products and toxic metals, unexploded ordnance removal, landfill remediation, removal of PCB contaminants, removal of pesticide and herbicide contaminants, and removal of solvent contaminants.

An example of one such site remediation project currently underway involves the removal of all unexploded ordnance. The Navy CLEAN Contractor,

WESTDIV, and the shipyard met late in 1993 to discuss the shipyard unexploded ordnance (UXO) problem. The decision was made at that time to take a different approach to the BRAC cleanup of UXO. The participants felt that a plan should be adopted that emphasized action (fast-track) instead of falling prey to the "study" mindset that has historically bogged down projects of this type. A relationship was formulated that would best utilize the available skills, time, and funding. It was decided that available resources would be shared among agencies (information, skills, etc.), and that environmental regulators would be kept involved in the planning process to apply their knowledge and experience in formulating an effective fast-track remediation and cleanup effort. As a result, a positive UXO remediation cleanup plan has evolved in a short period of time that effectively utilizes the resources and contributions of the Navy, the CLEAN contractor, and the environmental regulators.

An innovative site remediation proposal under consideration involves an investigation of the feasibility for using contaminated sand and/or soil from one site as a constituent in the remediation process at another site. The EPA's "presumptive remedy" to control landfill moisture intrusion and subsequent leaching of contaminants into underlying aquifers is to install a "cap" to seal the landfill. Subsurface "vertical cutoff walls" are also often used in conjunction with the cap to control lateral migration of the contamination plume. Typical cap and wall materials consist of concrete/bentonite and soil/bentonite mixtures. A number of sites exist on the shipyard that are contaminated with spent sand blasting materials that contain toxic metals. Studies are being conducted to determine if an acceptable method can be developed to solidify and stabilize these materials for use in landfill caps and vertical cutoff walls. If the method proves both feasible and cost effective, it would provide an innovative and holistic method of remediating two or more unrelated sites with a single process.

#### Asbestos Surveys and Abatement.

DoD policy is that property will not be disposed of through the BRAC process unless it has been determined that any asbestos present is not a threat to human health. Abatement work will be performed as necessary for asbestos that is damaged friable, and accessible.

The shipyard's current asbestos survey and abatement program began in 1989. It evolved from an organization primarily experienced in removal of shipboard asbestos.

working primarily with Naval Facility Engineering Commands, the shipyard asbestos teams are working on or have completed surveys and abatement for a total of about 2300 buildings comprising over 28 million square feet. On the shipyard about 1000 buildings require surveys and potential abatement for asbestos prior to closure.

In addition to providing a valuable source of projects to keep shipyard workers employed, the training and experience gained by asbestos program engineers and technicians has developed skills that will help these employees find employment upon leaving the yard.

#### Polychlorinated Biphenyls (PCBs).

Polychlorinated Biphenyls (PCBs) have been available for industrial use since about 1931. Unfortunately these chemicals were found to be hazardous to human health and the environment after their widespread use. In 1976, Congress enacted the Toxic Substance Control Act (TSCA) which directed U.S. Environmental Protection Agency to control the manufacture, processing, distribution, use, disposal and labeling of PCBs.

PCB contaminated transformers have been identified and are scheduled for removal prior to base closure.

The BRAC Environmental Technical Division is currently working on two PCB related projects: 1) a survey of mechanical machinery for possible contamination with plans for subsequent decontamination removal and/or disposal; and 2) an investigation of potentially PCB contaminated sites requiring possible remediation. Both projects have required extensive investigation and sampling. As a result, Mare Island employees have gained valuable experience in this highly specialized contemporary field of Environmental Engineering.

#### Historical Survey Project.

The historical significance of shipyard buildings is a major issue regarding ownership transfer agreements, base reuse, and potentially in evaluation of environmental remediation alternatives. BRAC Environmental has formed a team of 16 employees from various technical and production groups to survey and provide documentation for all buildings having possible historic significance. These survey personnel have received instruction and training in historical survey techniques from a UC Davis professor who is a state historical expert and landscape architect. In the course of performing the Mare Island historical survey,



the BRAC Environmental Historical Survey Section has computer-automated required state forms used for documentation of historic sites, buildings and artifacts, thereby reducing the time and cost associated with compliance with state requirements. BRAC Environmental has worked in close cooperation with the State Office of Historical Preservation (OHP), which has helped to accelerate the compliance process in keeping with the BRAC Environmental fast-track philosophy.

#### **BRAC Environmental Management Automated Information Systems.**

The BRAC Environmental Management Division has placed a high priority on providing state-of-the art information processing tools with which to work. Project managers and planners, using high powered personal computers, are utilizing the latest in word processing, database and spreadsheet tools to plan, manage and track their projects. All are connected to a Local Area Network (LAN) which permits the electronic exchange of information and use of peripheral resources.

Federal and State Environmental regulations are being made available over the LAN to instantly provide important reference and resource information to all personnel.

A Geographic Information System is being implemented to permit both subsurface and airborne contaminants to be tracked and managed, and to predict future conditions of contaminated areas based on sophisticated plume modeling techniques.

Finally, a document management system is being developed which will contain the complete text of all environmental documents and will permit the user to query by site, document type, contaminant, keyword or any combination of these to obtain required information.

#### **SUMMARY**

In an effort to implement the Presidents Five-part Plan, the shipyard's BRAC Environmental Technical Division has designated retraining and employment of its environmental workers as a primary goal of its charter. The rewards in this endeavor are many. Employees who complete academic course work in the BRAC Environmental training program to gain valuable on-the-job experience in the island's cleanup program. As a result, these employees develop very marketable skills for today's job market. Approximately 25% of the shipyard's environmental staff have been placed in jobs outside the yard since

closure was announced. Outplacement is expected to remain at a high level. Environmental training is a continuous process.

The shipyard has not yet required any forced layoffs due to base closure. None are predicted until the end in April, 1996. The ability to transition shipyard workers from production work to the environmental cleanup has resulted in a cohesive team effort on new projects. Morale in the face of closure is high. Base cleanup is on or ahead of schedule.



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## 3-D Computerized Measuring Systems for Increased Accuracy and Productivity in Shipbuilding and Repair

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### ABSTRACT

Conventional measurement and alignment methods for shipbuilding and repair are no longer compatible with today's technology. Measurements made with plumb bobs, taught wires, transits, optical-mechanical theodolites, levels and wooden templates, while adequate in many applications, are labor intensive and leave some redundancy with regard to accuracy.

With the increased popularity and use of the personal computer during the 1980's, several laser, electronic theodolite and photogrammetry based measurement technologies emerged. These methods require highly skilled workers, and although they increased the reliability of measurements, they are costly and again are labor intensive (Horsmon, 1991).

This report describes two computer based measurement systems. Each system requires only a single operator to generate three dimensional coordinates rapidly and accurately. Each system measures in the spherical coordinate system of the instrument. The supporting software programs allow for the transformation of the measured data to the blue print values or object coordinate system. Data can be imported from CAD or lofting software for measuring or locating specific points of interest, or can be exported for comparison of as-built coordinates with design values.

The choice of measurement system employed will depend on the task at hand, accuracy required, environment and budget of the user. Actual shipyard applications stating increased accuracy and/or productivity are cited for each measurement system.

### INTRODUCTION

This paper describes two proven approaches to making accurate three-dimensional measurements of large assemblies commonly encountered in a shipyard with a portable computerized system. One system is known as an enhanced single station electronic theodolite and the other as a laser tracker. Each system requires only a single operator. The measurement

philosophy is the same for each approach.

Each system measures distance based on properties of a beam of light being sent to a reflective target and then returned to its source. When the light wave is compensated for atmospheric conditions, differences between outbound and return signals resolve the distance to the target with extreme precision. The primary difference between the two systems is that the laser tracker distance sensor uses a laser beam projected to a corner cube target. The enhanced single station electronic theodolite distance sensor uses a modulated near-infrared light beam projected to a retro-reflective target.

### DEVELOPMENT OF TECHNOLOGY CLOSELY TIED TO SHIPBUILDING

The two technologies presented each have development roots within the shipbuilding industry and have been cultured for over a decade.

In 1982 a working group in the Super Modernization Committee of the shipbuilders Association of Japan, with the participation of Sökkisha Company, Ltd. (an instrument manufacturer), Ishikawajima-Harima Heavy Industries Company, Ltd. and three other shipyards undertook the development of a new measurement technique capable of measuring three-dimensional hull blocks of over 10 meters square within an accuracy of several millimeters (Masaaki, 1992).

As a result of this consortium, a distance-angle measuring instrument was introduced in Japan as a commercial product in 1989. The instrument is an enhanced electronic theodolite with a highly accurate near-infrared measurement sensor constructed so that distances are measured co-axially with the telescope line of sight. The instrument was integrated with an electronic notebook capable of recording field data and downloading this data to a personal computer with measurement and analysis software. This integrated system, named MONMOS in Japan, was introduced as a commercial product in 1990. There are over 200 systems being used in Japan today of which more than

50% are being used by shipbuilders.

This technology was introduced to the USA in 1991 by Sokkia Corporation of Overland Park, KS. In 1993, a robust measurement and analysis software product to support the Japanese made instrument was introduced. This MS-Windows® based software was developed jointly with TMA Technologies, Inc. of Bozeman, MT. The resulting industrial measuring system is used in many USA industries including several shipyards.

In 1983, Chesapeake Scientific Instruments, Inc., of Lanham, MD, undertook the development of an interferometer to track an object undergoing random motion to a measurement precision of .008 mm (.0003 in) to .08 mm (.003 in) in three-dimensional space. This work was performed in cooperation with MTS Systems Corporation of Minneapolis, MN, under a Navy contract directed by the NAVSEA Office of Robotics and Autonomous Systems. The resulting product was introduced commercially (Brown, 1986).

In 1988, a measurement services and software development company, Spatial Metrix, Inc. of Westchester, PA, began working on a rigorous MS-DOS® software product in cooperation with the manufacturer of the interferometer. The product was introduced commercially to support the laser tracker. Available as an option was a geometric dimensioning and tolerancing software package to perform inspections and report results. In 1992, the companies merged and the integrated company now located in Kennett Square, PA, is known as Chesapeake Laser, Inc.

Today's product accurately performs static (point to point) measurements and surface contour measurements (scan mode). The system software is an MS-Windows® application program which incorporates dimensioning and tolerancing operations based on ANSI Y14.5. Over forty of the current laser trackers have been delivered to the USA marketplace, including several shipyards, since 1993. The application software has been under continuous development and field testing since 1988.

The above mentioned companies were the pioneers of their respective technologies. Lieca of Unterentfelden, Switzerland, introduced a similar laser tracking system in 1993, and enhanced electronic theodolite measuring system with menu driven MS-DOS based software.

## PRINCIPLES OF OPERATION

Each 3-D computerized measuring system discussed consists of an instrument with angle and distance measuring sensors, a system controller (computer), measurement and analysis software, a power

source, and targeting. In most cases measurements can be made and recorded with each system by a single operator.

An electronic distance measuring sensor is mounted on a horizontal axis or trunion, so that it sweeps a vertical plane perpendicular to its axis of rotation and centered on a spindle or vertical axis of rotation. Mechanical construction requires that the trunion is precisely perpendicular to the spindle and that the sensor measurements are precisely perpendicular to the trunion. The reference point for making measurements is precisely at the intersection of the trunion and spindle axes. This is referred to as the instrument coordinate system origin. Encoders (precise angle measuring devices), each having an indexing capability, are attached to the trunion and spindle to accurately record the angular rotation of the distance measuring sensor about each axis.

An instrument of this design accurately measures a point of interest (P) in spherical coordinates with  $\Omega$  = azimuth,  $\Phi$  = zenith and D = slope distance. The spherical coordinates are then easily converted to cartesian coordinates; X, Y, and Z through the system controller (computer and supporting software) for analysis. The point of interest (target) is referenced to a three-dimensional, orthogonal coordinate system having its origin at the intersection of the trunion and spindle axes of the distance measuring sensor. This is designated as the instrument coordinate system (see Figure 1).

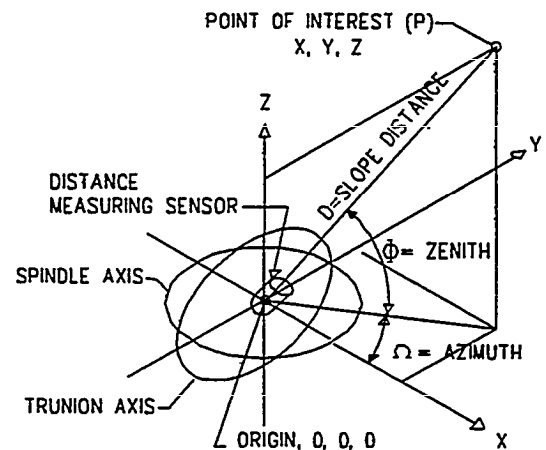


Figure 1 Instrument Coordinate System

For comparison and analysis, points of interest are most often required to be in the design or blueprint coordinate system of the object being measured, or a user defined coordinate system. Additionally, when measuring large objects such as encountered in shipbuilding, all points of interest cannot be measured from a single instrument location. The measuring system controller provides for finding the relationship between the instrument coordinate system and the user defined, or object coordinate system. Also, the relationship between an infinite number of instrument coordinate systems can be defined by the measuring system controller. The process of finding the relationship between coordinate systems and the relationship of points of interest in a coordinate system is known as a transformation or an orientation.

For analysis, the measuring system software allows the user to fit an array of targets to a variety of common geometric shapes using a least squares adjustment. Common shapes may be a line, plane, circle, sphere, cylinder or parabola. These analyses also provide the best-fit values of the parameters that define the shape and a listing of the residues that show how far each point of interest lies from the computed best fit shape. The software will also allow users to analyze the specific geometric relationship between points of interest, objects and shapes as well as the intersection of a point of interest with another shape or object.

The measurement system software allows a user to define the project parameters such as target measurement sequence, atmospheric corrections, axis labels and order, units angular and linear units of measurements and design values for points of interest.

Measurement project information can be printed at any time during or after the execution of a measurement task. Reports can include project parameters, targets, observations, shapes, transformations and comments. Project information can be reprinted to a specified database file or to a printer. Data base files can be imported and exported in AutoCAD or ASCII format.

### The Enhanced Electronic Theodolite

The single station theodolite is an enhanced electronic theodolite, which incorporates electro-optical modulated light technology based on a near-infrared light emitting diode. The distance from the origin of the sensor coordinate system to the target is measured co-axially with the telescope line of sight. The cross-hairs of the telescope are used to fix the azimuth and zenith position of the sensor. The absolute precision with which distances are measured from the origin of the sensor coordinate system is presently  $\pm (1\text{mm} +$

$2\text{ppm})$  while relative measurements of targeted points in an array are even more precise as residual errors in the measurement sensor tend to cancel out. This system uses disposable reflective targets backed by adhesive tape. The targets preprinted with a target pattern for registering the sensor's cross-hairs and feature a micro prism surface to return the distance measurement beam. Tooling targets and offset (hidden point) targets are also available. This targeting method represents a significant advance over the bulky prism targeting used for conventional total station type instruments which normally provide a fine precision of  $\pm 3\text{mm}$  ( $+ 0.118$  in).

The system consists of an enhanced electronic theodolite, industrial measurement software, computer, instrument stand and power source. When a portable notebook computer is used, the entire system can be DC powered, as the instrument can operate on a 6V DC NiCd battery thereby enhancing the portability of the measuring system. A 110V AC power supply is available as an option.

The software, specifically developed for industrial measurement performs all of the functions outlined under principal of operation. The 3-D measuring system features are presented for comparison in Table I.

### The Laser Tracker System

The laser tracker is a servo controlled HeNe laser interferometer which is locked onto the target by a servo feedback system. The servo motors drive the sensor's azimuth and zenith steering to keep in step with the target motion (if any). The HeNe laser interferometer determines the distance from the origin of the sensor's coordinate system to a resolution of  $1/4$  wave length of red light (0.1582 microns). The standard target, known as an SMR (spherical mounted retroreflector), is a hollow corner cube optic mounted in a 38 mm (1.5 in) diameter tooling ball. Mechanical centering and interfacing is within .01 mm (0.0005 in). Other target interface configurations are available. An offset is normally introduced between the center of the optic and the point of interest. The system software automatically corrects for this offset when indicated by the operator. Hidden points or surfaces not easily targeted with an SMR can be measured with an offset rod describing a sphere which centerlines at the point of interest or the newly introduced retroprobe based on the concept of a virtual image point.

**This system can operate in static (point by point) and dynamic(scan) modes. An SMR can be moved over surfaces and scanned by the laser to easily generate profiles for surfaces with complex contours.**

The standard servo system tracks the optical target to a resolution of 2.5 microns at a velocity of 4.0 meters per second. When three or more laser tracking units are used to track a common target, the measurement system is known as a trilateration system which will provide extreme precision in large volume applications.

A typical laser tracker 3-D measuring system requires 110/115 V AC power, and normally is configured to include a laser tracker (instrument), a tooling stand, a remote power supply, computer, software and appropriate targeting. The measurement function may be controlled from the computer, an umbilical cable or with an optional voice recognition system.

The software is an MS-Windows® measurement and inspection software application developed for the tracker technology, and performs all of the functions outlined under principles of operation. Additional features include reporting of feature construction and tolerancing operations based on the ANSI Y14.5 Geometric Dimensioning and Tolerancing Standard. Results are manipulated and reported in spreadsheet form. The laser tracker 3-D measuring system features are presented for comparison in Table I.

## APPLICATIONS TO SHIP PRODUCTION AND REPAIR

The applications of each technology to ship production and repair are only limited by the ingenuity of the potential user. Each 3-D computerized measuring system's software supports CAD and fairing programs for data exchange and comparison. The specific applications which follow provide evidence that accurate measurements, within the desired parameters, can be carried out by a single person in a shipyard environment.

### Welding Research and Dimensional Control Using the Enhanced Theodolite System

The enhanced theodolite 3-D measuring system has been used extensively in support of the Marc Guardian® Tanker project. This double hull design has been developed by Metro Machine, Norfolk, VA, and Marinex International, Inc., Hoboken, NJ. The research has been supported by The Carderock Division of the Naval Surface Warfare Center.

The double hull sub-assemblies incorporate

FEATURE	ENHANCED ELECTRONIC THEODOLITE	LASER TRACKING INTERFEROMETER
Distance Measurement Sensor	Electro-Optical with modulated near-infrared light emitting diode	Servo motor driven helium-neon laser interferometer
Optic	Telescope, coaxial light transmitting and receiving optic	Beam expander, Afocal, monolithic reflector
Distance Measuring Time	Static, one observation each 6 to 9 seconds	Continuous, 1000 points per second dynamic
Targeting	Microprism reflective disposable or tooling targets	Corner cube retroreflector positioned to .0005 to target feature
Measuring Range	100 meters (328 ft)	30 meters ( 100 ft)
Accuracy	$\pm(1\text{mm} + 2\text{ppm} \cdot \text{Distance})$	$1/10^6 \cdot \text{Distance}$
Power	6-12 VDC Std, 110/115 VAC Opt	115/230 Volts AC
System Weight	15.8 - 22.6 Kg (35 - 50 lb)	38.5 - 45.3 Kg (85 - 100 lb)
Set up time to begin making measurements	5 to 10 minutes	15 to 30 minutes (plus warm up time of 30 minutes (minimum))
Approximate Cost (1994 Dollars)	\$35,000 to \$50,000	\$140,000 to \$180,000

Table I Feature Comparison, Laser Tracking Interferometer and Enhanced Electronic Theodolite

2.4m (8 ft) wide by 15.2 m (50 ft) long slightly curved shell plates in place of typically used flat plates. The curvature design, less than .15 m (3 ft) over the 2.4 m (8 ft) width, increases the resistance to deformation, thereby eliminating the need for longitudinal stiffeners other than along the shell plate edges. A reduction in structure weight, welding and fitting is achieved by this proprietary design. Structure welding is done with an automated welding process, simultaneously welding the inner and outer hull plates along the 15.2 m (50 ft) length of a 2.1 m (7 ft) high stiffener. The standard modular 2.1 m (7 ft) by 2.4 m (8 ft) by 15.2 m (50 ft) cubicles are then incorporated into 136-317 metric ton (150-350 ton) double hull subassemblies up to 61 m (200 ft) wide by 30.5 m (100 ft) high by 15.2 m (50 ft) long modules.

The enhanced theodolite 3-D measuring system was used to provide data regarding shrinkage of the shell and stiffener plates during the automated welding process. This data was required to engineer the final design dimensions of the shell and stiffener plates to meet a desired cubical dimensional control of  $\pm .8$  mm ( $\pm 1/32$  in) and module dimensional control of  $\pm 3.1$  mm ( $\pm 1/8$  in). Normally, during this measurement process, over 100 points of interest per hour were observed and recorded for later analysis by a single system operator.

**This 3-D measuring system was also used daily** to construct welding towers for the massive module assemblies, position 6.4-45 metric ton (4-5 ton) shell and girder plates into the fixture, provide verification of dimensional control prior to welding, and provide as-built dimensions of cubicle sub-assemblies for computer modeling of sub-assembly fits to complete the modules.

#### Inspection of Carrier Catapult Control Monuments Using the Laser Tracker

Newport News Shipbuilding, Newport News, VA, has contracted for the laser tracking to execute their highly accurate control surveys for their aircraft carrier catapult alignments since 1991. The catapult troughs are over 76 m (250 ft) in length, about 1.5 m (5 ft) wide and set below the carrier deck surface about 1.2 m (4 ft).

Accurate measurements by conventional techniques is nearly impossible given the geometry of the trough, the pitch and roll of the ship and the working environment. The laser tracker measurements are taken after sundown, to eliminate the effects of the sun on the ship structure. Measurements must be made within time constraints to eliminate the effects of extreme temperature fluctuations during the measurement process. Nearly 50 control monuments are

measured for each catapult. The control monuments are nominally in line, vertically and horizontally. The in-line measurement capability of the laser tracker allows highly precise and efficient collection and analysis of the required data.

Evidence to support the accuracy of the technology and procedure employed is supported by a comparison of data gathered during two different control surveys of the same catapult. An initial survey was accomplished in the summer of 1991, and another survey of the same catapult was completed during the winter of 1993. The largest RMS residual error of the three-dimensional coordinates between the two data sets was 25 mm (0.010 in) over the 85 m (280 ft) survey.

#### Conclusion

The availability and value of increased accuracy control through emerging technology should not be overlooked by the ship production industry. It has been shown that precision 3-D accuracy control leads to fewer man hours to accomplish specific fabrication, machining or positioning tasks thereby increasing productivity. Residual benefits can include less re-work, trimming, fitting and immediate comparison of as-built with design values. **Quality assurance procedures are easily documented and stored on disk.**

Measurements of large objects can be performed by a single system operator with the measurement systems described herein. The operator need not be highly skilled in engineering or computer techniques to perform accurate measurements. End product knowledge, training, aptitude, common sense and a desire to apply new technologies will lead to increased productivity.

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# Spanish Shipbuilding: Restructuring Process and Technological Updating From 1984 to 1994

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## ABSTRACT

In 1985, the Spanish commercial shipbuilding sector initiated a wide restructuration program due to the deep crisis sustained from 1975 as a consequence of the surplus shipbuilding capacity and an order book reduction related to the oil crisis.

This restructuration program has been developed in several phases, the main features of which are related to capacity and workforce adjustment by one side, and technological updating by other side.

Therefore, this paper has been prepared to give a general view of the different steps carried out by the Spanish commercial shipbuilding sector for accomplishing a more competitive industry, according to the actions realized in the European countries and the characteristics of the Spanish political, economical and technological situation.

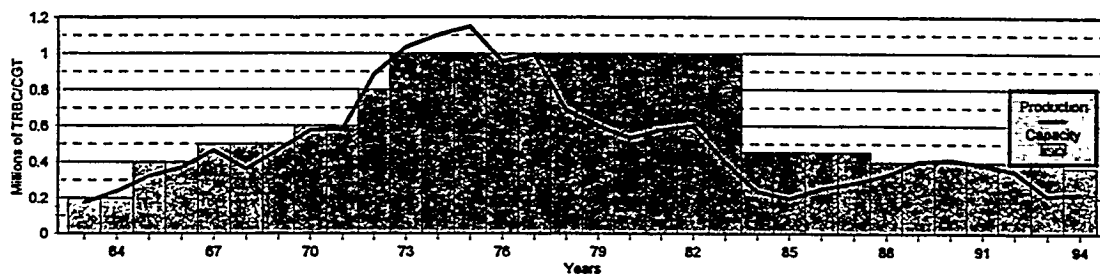
## BACKGROUND

The Spanish shipbuilding sector had an intense increase in capacity during the middle of the 60s.

It was a period of strong economic growth in Spain during which the Spanish authorities considered that the shipbuilding sector could act as the propeller of the development of the whole Spanish industry, thus the shipbuilding sector benefited from strong support.

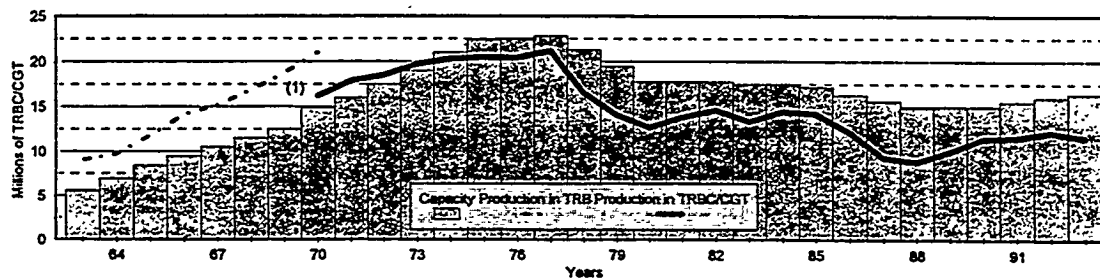
Therefore from 1963 until 1973 the shipbuilding capacity in Spain multiplied by 5, overtaking 200,000 CGT to more than a million. The 70s was the most brilliant period for Spanish shipbuilding, occupying a place among the first five countries in worldwide production ranking with Japan, Sweden, Germany and United Kingdom.

This increase in Spanish shipbuilding capacity from 1963 to 1973 had its parallelism worldwide due to the fact that the global production multiplied by 4 during this same period ( See Figures 1 and 2).



Source : Shipbuilding Sector Agency

Figure 1 Spanish Shipbuilding Capacity and Production



Source : AWES, Lloyds R.S., Shipbuilding Sector Agency

Note 1 : Before 1970 there are data of Worldwide production only in TRB

Figure 2 Worldwide Shipbuilding Capacity and Production

But, it was about 1976 when the reduction of production and capacity, worldwide, began. The oil crisis of 1973 was the main cause of the shipbuilding crisis which has continued, with small fluctuations, for more than 20 years with a strong unbalance between supply and demand. That was provoked by the creation of a great number of shipyards for the construction of large oil tankers, which then had to dedicate themselves to the construction of other types and sizes of vessels. That gave way to the proliferation of subsidies worldwide with, luckily, will disappear at the beginning of 1996 thanks to the Organization for Economic Cooperation and Development (OECD) agreement reached in July of 1994.

This crisis provoked a workforce reduction of the shipbuilding sector with the OECD countries of 50% between 1976 and 1984, a percentage which was nearly accomplished as far as the capacity reduction of the OECD shipyards was concerned. Spain was, however, an exception since during the 1976-1984 period, only a 3.7% general workforce reduction was produced and still maintaining the construction capacity (see Figures 3 and 4).

However not being able to keep production according to its capacity, the Spanish shipbuilding sector suffered economic and technological decline. This changed in 1985 with the start of the first Phase of Restructuration that ran from 1984-1987.

The cause of this important delay in starting the restructuration of the shipbuilding (and the Spanish industry generally), was the political and economical transition process which happened in Spain as a consequence of the change in the political control which occurred in 1975. Neither the political parties nor the Spanish trade unions were in a condition to simultaneously afford both the process of political change and the industrial restructuration. That would have provoked strong labor disputes increased by the fact that the industrial restructuring process coincided with the return of a great number of Spanish workers who were emigrants in European countries also involved in their own industrial restructuring processes.

In 1984 extensive negotiations took place among trade unions, employers and the Spanish Administration, concluding on the necessity to

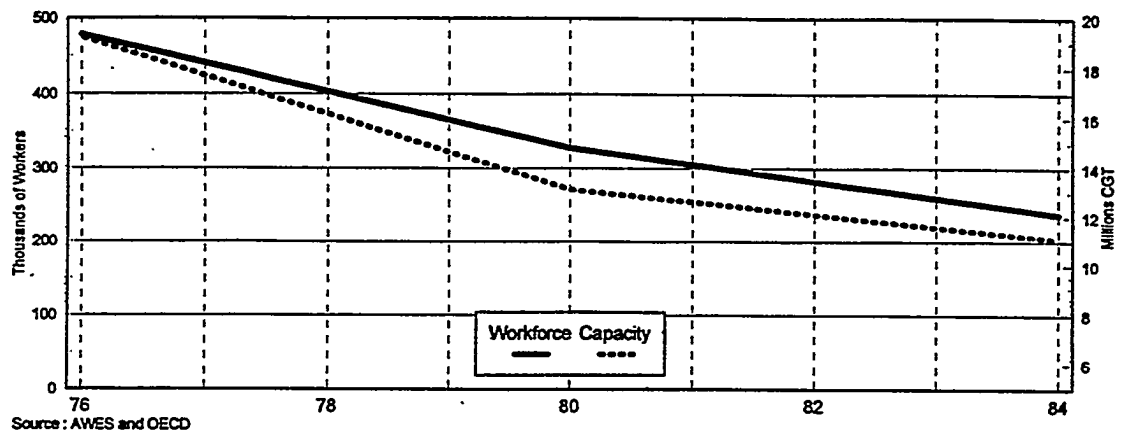


Figure 3 Capacity and Workforce Reduction in O.E.C.D. (From 1976 to 1984)

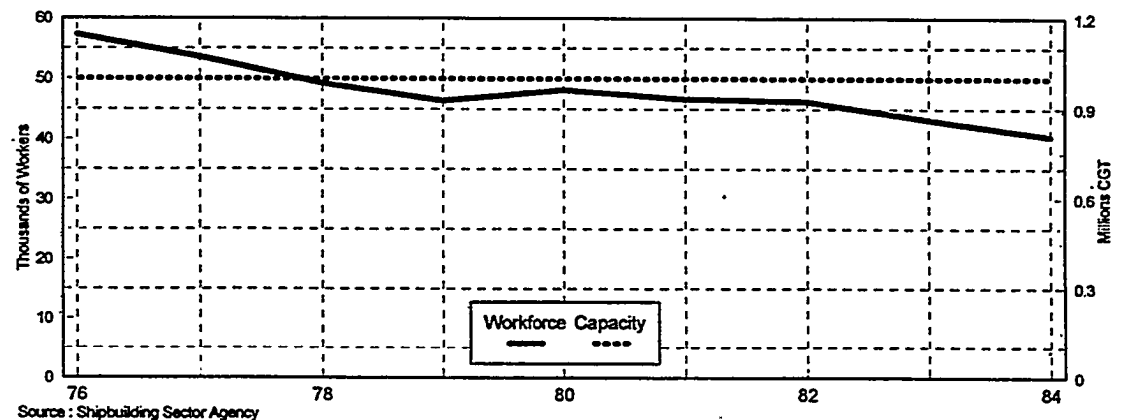


Figure 4 Capacity and Workforce Reduction in Spain (From 1976 to 1984)



undertake an intense process of restructuring in shipbuilding. At that time the situation was the following

1. An excess of workforce of nearly 40%,
2. An excess of capacity of 55%,
3. A serious technological deficiency due to lack of investment made in the previous decade,
4. An important economic decline, especially the public sector, and
5. A decline of commercial image.

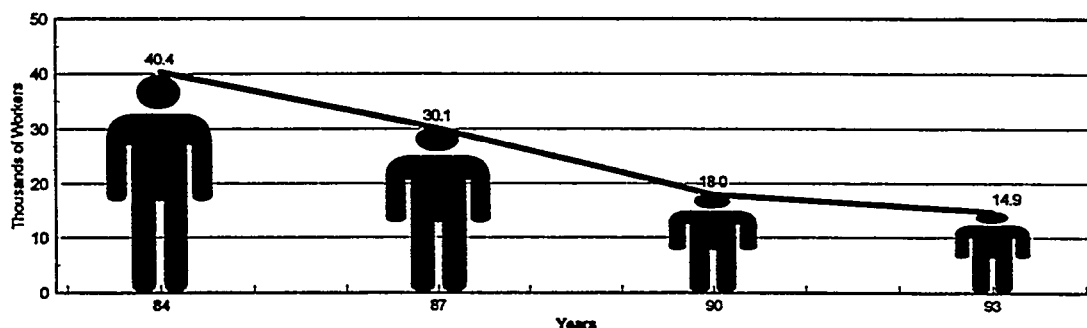
In order to carry out the shipbuilding restructuring process, the sector was subdivided into two subsectors of different characteristics: one being the big shipyards, all of them of public capital, and the other of small and medium shipyards, where the majority belong to private capital (except three of them). Both subsectors were similar in capacity and workforce, although technologically they showed certain differences in favor of the big and medium shipyards belonging to the same business group.

#### FIRST PHASE OF THE RESTRUCTURATION FROM 1984 TO 1987.

The serious initial situation of the sector was obliged to approach all problems simultaneously still knowing the serious difficulties consistently with the trade unions and workforce situation nationwide. Fortunately, after hard worldwide negotiations, agreements were made with most representative trade unions without whom it would have been impossible to imagine any restructuring plan to be presented.

The restructuring plan in this first phase was basically confined to the following

1. Reduction of the workforce from 40,000 to 30,000 workers, mainly by means of pre-retirement (25% reduction) (see Figure 5); and



Source : Shipbuilding Sector Agency

**Figure 5 Workforce Reduction in Spain (From 1984 to 1993)**

2. Closing of capacity from 1,000,000 CGT down to 445,000 CGT by means of closing 6 shipyards and changing activity of two big shipyards from new construction to repairs and/or off-shore.(See Figure

1)

This phase coincided with a declining market situation worldwide, so production maintained inferior levels to the defined capacity for the sector.

From the technological point of view in analysis of this first phase, it is more appropriate to subdivide the sector between public and private shipyards. The two groups of shipyards are analyzed as of 1985:

#### Public shipyards

The public shipyards lacked, at the beginning of the reconversion, the following technological matters:

1. They lacked advanced computer applications of the CAD/CAM type. Design processes were done by a traditional method of systems.
2. Building of a hull was done by means of blocks, although these were manufactured with overlaps. The level of preoutfitting was low.
3. Planning wasn't very functional due to the variability of the building processes.
4. Quality, limited itself to the control functions, which was carried out "posterioris", that is to say after a product was made.
5. The levels of training and multifunctionality of staff were quite low.
6. In the commercial area, the response capacity was low and the marketing deficient.
7. In the area of purchases, delays with supplies were frequent.
8. As far as the means and layout installations were concerned, there was a need to replace obsolete machinery, redistribute the flows of the materials, extend workshops and generally improve installations.

#### Private Shipyards

Given the greater diversity of the private shipyards

subgroup, it is difficult to do a homogeneous analysis of its situation, but some common aspects can be pointed out which allow identification of the

technological level of this group, which on average was inferior to the public shipyards. Their main limitations are listed below

1. The practice of computer applications with regard to calculation or basic design was absent; the ship drawings were done by the traditional procedure of systems.

2. For hull construction, flat blocks were premanufactured, but, in general, curved blocks were not. Fitting of steel plates on curved blocks was done on building berth. Preoutfitting, generally, did not exist.

3. Marking and cutting processes were done in the smaller shipyards by hand and to a scale of 1:1; in the bigger ones, to a scale of 1:10 together with cutting by machinery of optic control.

4. Primary welding was done manually, plate welding was done on both sides.

5. Management and control systems were deficient.

6. Quality was reduced to those controls required by the rules.

7. The levels of staff qualifications were relatively low.

8. Portable equipment, especially adapted tools, were scarce.

9. The commercial area was limited due to the fact that with small shipyards, they usually relied on traditional clients, in close geographical proximity.

10. Finally, shipyard physical plants suffered from many shortages, especially in workshops means of lifting, transport and machinery, were especially lacking.

In this period, investments were scarce due to shipyard situations. Most of the investments were dedicated nearly exclusively to the recovery of obsolete industrial equipment. Productivity levels improved nearly exclusively due to workforce reductions.

## SECOND PHASE OF RESTRUCTURATION FROM 1987 TO 1990

The intensive workforce and capacity adjustments done in the previous period put the sector in a more comfortable position to compete in the market, but there were still serious problems which, were still more changes required

1. Additional workforce adjustment
2. Additional capacity adjustments,
3. Industrial investments,
4. Staff training, and
5. Improvements in marketing activity.

Spain was incorporated into the European Economic Community (EEC) in 1986. New restructuring programs for the shipyards were presented, but this time within the EEC Directive for Shipbuilding Aids. The following results were achieved due to these programs

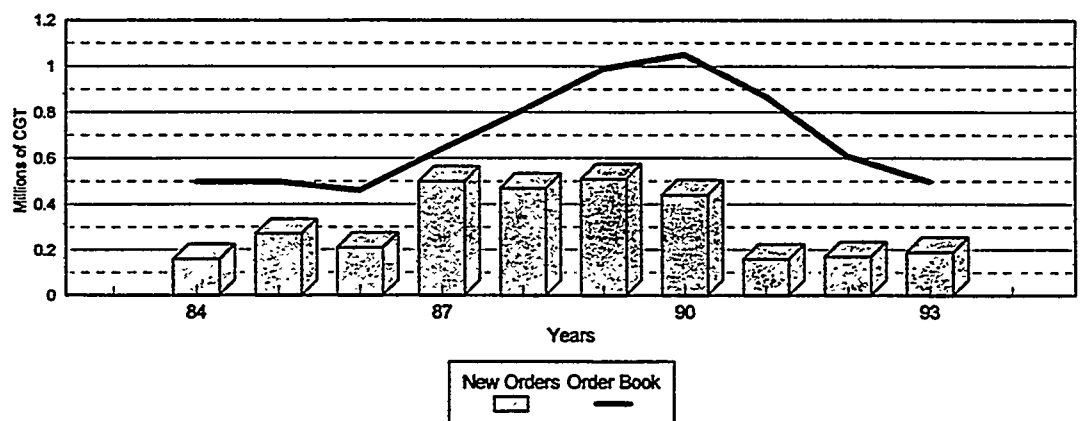
1. Additional workforce adjustment from 30,000 to 18,000 workers (55% from the 1984 situation), were made. (See Figure 5).

2. Additional closing of capacity from 455,000 CGT until 400,000 CGT (60% over the initial situation) was effected by closing another 7 shipyard: definitely and changing the activity of another shipyard to repairs. (See Figure 1).

3. New investments, especially in industrial installations (60% of the total) corresponding to 70% over the foreseen programs and a total of around 3% of the shipbuilding sector turnover.

4. Staff training was started for those who remained in the shipyards where the workforce structure, after the strong adjustment of the previous period, was mostly unbalanced.

5. A favorable order book was secured in the 87-88 period (see Figure 6) due to:



Source : Shipbuilding Sector Agency

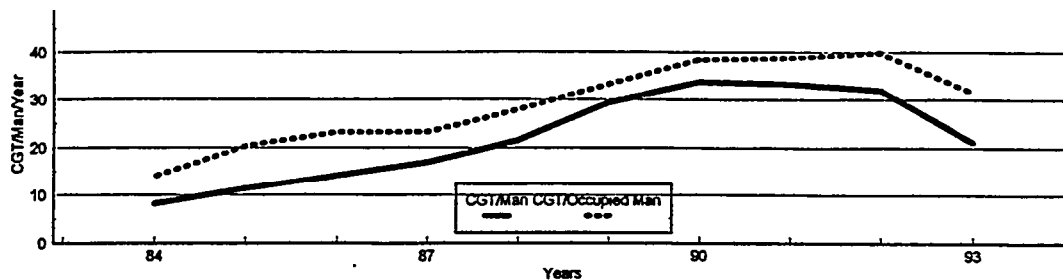
Figure 6 Total Order Book and New Orders in Spain (From 1984 to 1993)

- improved competitive position,
- productivity improvements,
- improved commercial activity, and
- greater aids authorized by the EEC in the frame of the Community Directive.

6. Production levels during the years 1989 and 1990 were within the maximum limits of capacity established for the sector. (See Figure 1).

7. An important increase of productivity levels reached in 1989 and 1990 a figure close to 30 CGT/man/year, which had been considered a goal. (See Figure 7).

Impact, which contemplated those innovative measures in the organization of workshop flow and the updating of the installations to new manufacturing procedure, Horizontal, seeking the best competitiveness via new methods of development, management and manufacturing procedures and systems as well as the specific training on these technologies and the development of new products; Restructuration, which included those actions obliged by the targets and necessities of the Restructuring Plan undertaken by each shipyard;



Source : Shipbuilding Sector Agency

**Figure 7 Productivity Level in Spain (From 1984 to 1993)**

Before starting this second phase, the Shipbuilding Sector Agency carried out a diagnosis of the technological situation which suggested taking two types of actions of urgent nature. One being the "soft" type, destined to make good the most urgent shortages of design and management. The other being the "hard" type to update the equipment and installations which was most needed in order to ensure a minimum level of quality and productivity.

Regarding the private shipyards, due to their dispersion, the work of the Shipbuilding Sector Agency consisted, in a first stage, not only in the specific definition of the type of projects to be developed, but, in certain cases, in the concrete definition of the fundamental characteristics of some projects, together with the coordination of the same. It was in these shipyards where most of the effort was carried out on "soft" actions starting with the umbrella projects. The public shipyards also participated in these projects, though at a different level. The most important projects were, in the area of CAD/CAM, Management Control, Welding, Quality and Applied Investigation.

As far as the development of the "hard" type was concerned, it was different between the public and private shipyards since the initial situation was as well.

#### Public shipyards

The public shipyards established five areas of investment performance, classified in the following way.

Replacement which were aimed at keeping the availability of equipment, installations and existing tool kits; and Safety and Social Health, whose target was to improve the working conditions and the personal safety of the shipyards.

As far as the distribution of these investments, cost wise, it is shown in Table I:

Impact	Restruc.	Horizontal	Replac	Saf.	Total
29%	41%	9%	16%	5%	100%

Table I Distribution of Investments

In this phase, 70% of the investments were in the restructuring and impact areas, due to the important adaptation which had to be done in the installations, which were obsolete or generally not adequate enough.

#### Private Shipyards

As far as the private shipyards were concerned, in this period the primary investments were in workshops especially in steel processing machinery and, general services. Another significant area of investment was in computer systems and equipment. Investments are summarized in Table II:

CONCEPTS	1987(%)	1988(%)	1989(%)	1990(%)	AVERAGE(%)
BUILDING & OFFICES	8	14	6	6	8
LAYOUT AND GENERAL SERVICES	8	13	19	11	13
STEEL & FITTING WORKSHOP INST.	34	39	35	32	35
MACHINERY	43	20	24	38	32
COMPUTER	7	14	16	13	12

TABLE II PRIVATE SHIPYARD INVESTMENTS

One can see the importance of investments in workshops; though 80% of such value corresponds exclusively to steel workshop installations; then the important volume of the machinery investment, especially for hull processes (the one dedicated to lifting means, being very important).

### THIRD PHASE OF RESTRUCTURATION FROM 1991 TO 1993.

With regard to the global parameters, the Spanish shipbuilding sector achieved during the 1985-1990 period what the majority of European countries had achieved in 15 years, but with the following added difficulties.

1) A legislative as well as trade union work frame was more rigid than in other European countries. The work adjustment, therefore, has been more costly, slower, and less selective.

2) Location of the shipyards was in areas where they coincided with other restructuring processes with few reemployment alternatives (absolute absence of emigrant workers as with other European countries). There were strong unemployment level in such areas.

3) There were budget difficulties in the Spanish Administration to afford the restructuring achievements in such a short time, That caused a financial cost increase for the shipyards.

4) Continuation in other competitor shipyards from the EEC and Far East, of the productivity improvement processes which obliged the Spanish to establish more ambitious goals than those initially foreseen.

Due to the aforementioned, the Shipbuilding Sector Agency instructed the shipyards to present the performance programs for the 1991- 1993 period according to the following goals

1. The maintenance of the global capacity of construction;
2. Additional adjustment of workforce;
3. Detailed programs of technological

improvement concentrating with more intensity on the improvement of the work organization, specifically in:

- Production Oriented Design,
- Application of Group Technologies,
- Application of Dimensional Control, and
- Application of Total Quality

Management;

4. Assets investment programs;
5. Training of workforce;
6. Cooperative Marketing; and
7. Shipyards collaboration for combined use of

assets.

The results achieved were the following.

1. Construction capacity was maintained at full production until 1992. Then it descended substantially. (See Figure 1)

2 The workforce dropped from 18,000 to 14,900 workers (a 63% drop from the start of the reconversion). (See Figure 5)

3. The average productivity of CGT /man/year until 1992 inclusive, maintained itself within the foreseen goals, having exceeded the 30 CGT/man but dropped in 1993.(See Figure 7).

4. The shipyards invested 90% of the total value foreseen in performance programs which represented 7% of the average turnover of the sector.

However during this period there were a series of difficulties which deteriorated the achievements obtained up to 1992. Contracting from the years 1991 to 1993 was very low due to:(See Figure 6)

- excessive strength of the peseta;
- depression of the national and international market, most of all during the years 1991 and 1992
- Budget difficulties which have affected the financing of the vessels and the financial costs of shipyards
- Strong decrease of the aids ceiling in the Community Directive, and
- Non-fulfilment of the marketing programs of the shipyards.

If the production of the years 1989 until 1992 had been close to saturation due to the order book which

was achieved during the years 1988 to 1990, 1993 was a very bad production year because of lack of contracting, starting from 1991, which has contributed to a worse economical situation of the shipyards in 1993.

The technological situation in this third phase (having finished the previous one mainly concentrated on installation investments), started with a different orientation. For this reason, the shipyards were asked for updated technological programs, which previously had been examined by the Shipbuilding Sector Agency for the purpose of introducing the new constructive methods, group technology, production orientated design, quality, management and control systems.

The above mentioned technology programs were divided into three main concepts or types of investment

1. Investment in installation equipment and machinery;

2. Actions on improvement of organizations, of management and technological and

3. Actions corresponding to training courses and programs of work safety.

To summarize, Tables III and IV reflect some basic data of the technological programs developed during the 1991-1993 period, corresponding to the three concepts above. After carrying-out of technological programs from the 1991-1993 period, the shipyards situation can be summarized as follows.

#### Public Shipyards

1. The constructive methods have been practically implemented by zones and stages.

2. CAD/CAM systems are being widely applied.

3. The control and management systems have been brought up-to-date by means of computerization and the establishment of evaluation parameters.

4. The manufacturing processes have been standardized and dimensional precision has improved by means of statistical control of processes. Modular manufacturing has increased and high preoutfitting percentages have been realized.

5. Various shipyards have achieved certificates of Quality Assurance Systems ISO -9000.

6. Nearly all the welding is semi-automatic and automatic

7. The dimensional precision of curved plates has improved by means of 'line-heating' application.

8. The level of knowledge of the workers has widened, allowing establishment work systems by multifunctional teams.

9. Total Quality Control (TQC) techniques are being applied for the introduction of continuous improvement systems. Likewise, the old system is being replaced by an autocontrol.

P u b l i c	CONCEPT	TOTAL NUMBER OF PROJECTS	% OF ALL PROJECTS	% COSTS
	1	523	33	34
	2	737	47	38
	3	318	20	8
	<b>TOTAL</b>	<b>1578</b>	<b>100</b>	<b>100</b>

TABLE III

P R i v a t e	CONCEPT	TOTAL NUMBER OF PROJECTS	% OF ALL PROJECTS	% COSTS
	1	426	48	61
	2	263	30	25
	3	192	22	14
	<b>TOTAL</b>	<b>881</b>	<b>100</b>	<b>100</b>

TABLE IV

10. The supply terms of vessel equipment have improved considerably at the same time as improving the suppliers qualification.

#### Private Shipyards

This group of shipyards that started from a technological situation that, in general, was worse than the public one, have accomplished a very significant progress in this area. The most relevant investments were of type 1 in installations, equipment and machinery. However, regarding type 2 and 3 investments, important progress has also been made.

For the type 2 projects, and given the dispersion of the private shipyards, joint projects between various shipyards have been organized.

After the technological programs of the 1991-1993 period, the average global situation of these shipyards is as follows. .

1. Most of them have CAD/CAM systems.
- 2 They find themselves in an initial phase of application of group technology, having increased substantially the level of preoutfitting.
3. The complete building of hulls is being done by means of prefabricated blocks. The application of line-heating techniques has improved quality considerably.
4. The use of semi-automatic and automatic welding has increased considerably. At the same time, one side plate welding processes with backing have increased.
5. The management control and planning systems have improved.
6. The training of the workers has allowed for a higher level of multifunctionality.
7. Quality assurance systems are being introduced. Several shipyards have certificates, type ISO-9000.
8. Installations, equipment and means have improved the flow of materials and eliminate bottle necks.

#### CURRENT SITUATION

The decline suffered in 1993 due to the high grade of sub-activity, which still will not be fully resolved in 1994, warrants reconsideration of the restructuring plan of the Spanish shipbuilding sector. The extension of the EEC Directive until the end of 1994 has allowed the Shipbuilding Sector Agency to ask the shipyards to extend their programs foreseen for the period 1991-1993, until the end of 1994. The Agency has held several meetings with the shipyards in order to try to define such performance which, in general terms, consists of:

1. An additional adjustment of workforce,
- 2 Continuation of the technological improvement, but exclusively in aspects related to the

organization of work and training of staff (more investments in assets are not considered necessary at present);

3. More ambitious programs of marketing and

4. Collaboration between companies (geographically or by market type).

During 1994, the technological programs have been continuing from the 1991 -1993 period, though certain specific redirection had to be given. Specifically, and according to the current situation of the world market, these programs include, the following actions:

1. Activity plans of marketing and sales;

2 Plan of improved technology, concentrated on the introduction of the new building methods and quality systems, as well as the training of workers; and

3. Collaboration plans between companies in areas such as marketing, technical offices, purchases, production, technology, subcontracting, etc.

One of the most significant aspects of the current situation is the great importance that the Spanish Administration is giving to the marketing and commercial actions. In this sense it is important to point out that, favored by the Shipbuilding Sector Agency, a group of 10 shipyards has made a joint society for the elaboration and application of a global policy of marketing.

One other aspect which is being given great importance is the staff training in order to get better qualified as well as more competent and motivated workers. Another field which needs to be influenced is innovation of products. Moreover, the effort to improve quality continues, not only with shipyards, but also suppliers. After staff adjustments, the shipyard corresponds more and more as a 'synthesis business', where much of the manufacturing is external and it is in the actual shipyard where it is matched and coordinated for building up the ship.

#### CONCLUSION

The intensive restructuration of the Spanish shipbuilding industry, has been accomplished in a relatively short time compared with the same process in the other European countries. However, it is necessary to continue in this way in order for this sector become an effective synthesis business. Therefore, the following actions must be carried out:

1. To continue with the workforce adjustment up to the maximum compatible with the synthesis capacity

2 To continue with the workers training, and the recruitment of young and well qualified workers.

3. To maintain a constant effort to improve the production organization and the introduction of new technologies for building.

4. Incorporation of suppliers into the building process itself is fundamental in a "synthesis business" that shipbuilding is becoming.

5. Efforts of new technologies have to be done not only in CAD/CAM and/or use of robots, but also in process technologies like welding bending, handling of equipment, safety in work etc;

6. Training of workers in new systems and processes is essential for the introduction of the same.

7. Cooperation of the technical offices in the investigation and development of new products, and collaboration with university bodies and investigation institutes, shall be an important factor for competitive improvement.

8. Commercial and marketing actions must be sufficiently endowed to attend to market needs. These actions should be orientated to the maximum joint participation of the shipyards.

9. The Investigation and Development I&D, programs must be open for the adaptation of the technologies of other industries, where application is considered to be relevant for shipbuilding.

Finally, and in order to ease the application of realignment in shipyards, it is considered necessary to have a promoting and development system that contemplates the proper needs of shipyards, and eases the transfer and fitting of technologies used in other more advanced shipyards, or in other industries.



## The Netherlands' Shipbuilding Industry: Own Solutions to Competitiveness

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### ABSTRACT

shipyards in the Netherlands rely on a flexible **infrastructure** of subcontractors, colleague yards and manpower pools temporarily increase their capacity. In addition, the industry has developed some unique concepts with respect to marketing, and to facilitating enterprises for design and engineering, partial work preparation parts fabrication, hull election and outfitting.

The paper will address the subject of competitiveness in shipbuilding and the factors which determine the strategic competitive position of shipyards. The applicability of various simple models, which can be used to describe shipyards' strategic market positions, will be discussed. In particular, a model addressing a ship's life-cycle will be detailed. The paper will further focus on solutions, which were generated by the shipbuilding industry in the Netherlands, in its strive to achieve and maintain a competitive position in domestic and world markets.

### INTRODUCTION

In general the market position of enterprises is determined by the factors of price, delivery time and quality. After-sales services and often financing are additional factors. However, these factors do not determine adequately the market position of shipyards. This position must, in one way or another, address some cyclic process, related to the product of interest, the ship.

The overall competitiveness of shipyards can be associated with the following (ship) buying model (Peat Marwick, 1992):

1. Initial business case (feasibility study, concept design)
2. Selection of yards to
3. Shortlisting (delivery time, acceptable specification price indication);
4. Negotiations with shortlisted companies;
5. Final shortlisting (product performance, cost to owner, delivery cycle);
6. Final design engineering and commercial evaluation; and
7. Decision.

Shipyard competitiveness is clearly determined by the ability to satisfy the governing selection criteria at each stage of the buying model. Stages 3, 4, 5 and 6 relate with the factors price and delivery time, whereas the factor quality can be interpreted as the competitive edge obtained by offering an innovative ship design (Peat Marwick, 1992). The key issue is the consideration of being shortlisted and finally on the short list (stages 2 and 3 of the buying model). According to the Peat Marwick report, the applicable criteria address, respectively, market access and marketing issues.

The access to markets is a rather complex issue, which involves matters of national industry "policies, home credit schemes and other forms of subsidies, financial links between ship owners, Shipyards and finance companies, etc. Marketing issues address the ability to be in constant touch with shipowners in order to inform them about yard capabilities on product innovation, price and delivery time. According to Peat Marwick, ... the advantages of regular contact are seen by shipowners as being:

1. helpful in building market knowledge,
2. helpful in shaping the design concepts the Owner is working on and
3. helpful in making the decision of when to place the order".

Obtaining access to markets is obviously not included in the ship buying model, which means that this model has limited value for the strategic market positioning of shipyards.

### STRATEGIC POSITIONING

A study on strategy determination and strategic positioning of shipyards in the Netherlands from the late eighties (Van den Tom & Bunigh, 1987) puts forward two elements, which can be used to identify basic strategies in shipbuilding; these are:

1. The performed activities or functions, and
2. The ship type.

Shipyards can choose to any out less or more activities in the process which leads from conceptual design to production.



These activities are:

1. Concept development,
2. Preliminary design,
3. Final design,
4. Detail design (work drawings), and
5. Production.

On the basis of these activities three principal strategic business positions are possible, see Figure 1. Position A implies the delivery of a complete solution to the (ship)owner. Position B implies the delivery of a product which is based on a concept solution provided by the (ship) owner. Position C implies the delivery of a product which is based on a complete (final) design solution provided by the (ship) owner.

The second strategic element is related to a ship's complexity which gains importance when associated with the differences between shipyards regarding the following factors:

1. Product technology, including ship machinery, systems, etc.;
2. Know-how regarding performance criteria;
3. Price variations; and
4. Ship production technology.

A global distinction between ship types is:

1. Non-cargo ships incorporating advanced technologies (work vessels, drilling, naval, etc.);
2. Specialized cargo ships (LPG/LNG, refrigerated, chemical cargo, etc.); and
3. General cargo ships.

Following Van den Tom & Bunigh, four basic strategic market positions can be determined on the basis of principal market positions (shipyard activities, Figure 1) and Ship types, these are shown in Figure 2.

Several comments can be made with respect to Figure 2.

1. The factor quality dominates the upper half of Figure 2, whereas the factor price dominates the lower half.
2. Developing countries are located mainly in the lower half of the Figure; however, their position tends to move towards the upper half.
3. Strong market positions which are not easily overrun by the competition are position (1) and (2), because these positions rely on proprietary knowledge.

	positions:	A	B	C
concept development		x		
preliminary design		x		
final design		x	?	
detail design (engineering)		x	x	?
production		x	x	x
x : performed activity ? : optional activity				

Figure 1: Strategic positions on the basis of shipyard activities (Peat Manwick, 1992)

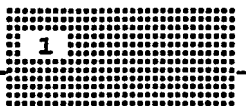
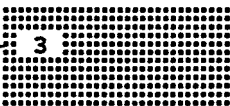
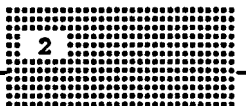
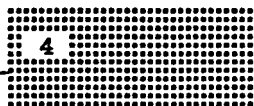
activities>	position A*	Position B*	position C*
nom-cargo ships			
specialized cargo ships			
<b>general cargo ships</b>			
1. Builder of innovative specialized ships 2. Builder of standard ships 3. Builder of relatively complex one-of off's 4. Jobber; no own product		* principal market positions from Figure 1	

Figure 2: Basic strategic positions

1. Definition of needs,
2. Definition of product or design,
3. Product realization or production,
4. Product exploitation, and
5. Product scrapping.

These links are shown in Figure 3, from which several possible strategic positions can be deduced. These positions address the role of shipyards with respect to ship life-cycle and with respect to other cycles which link with the latter. Three examples are given.

This position is located within the third stage of

Maritime technology prime contractor.

## Maritime technology prime contractor plus

This position which is similar to that of the maritime technology prime contractor, but includes knowledge on ship's exploitation and links with the corresponding cycle. This position addresses primarily industrial vessels, such as dredges, fish catching and fish processing VCSes, and many others. It is also strongly related to the factor quality.



	ship's life-cycle stages				
	stage 1	stage 2	stage 3	stage 4	stage 5
. clear business strategy focusing on core product markets	■■■■■			■■■■■	
. marketing program, product development, after-sales services	■■■■■	■■■■■		■■■■■	
. purchasing policy		■■■■■	■■■■■		
. human resources management		■■■■■	■■■■■		
. design and technical systems	■■■■■	■■■■■	■■■■■		
. planning and production engineering		■■■■■	■■■■■		
. appropriate production facilities, technologies, automation			■■■■■		

Figure 5 Strategic elements according to Peat Marwick and the relation with a ship's life-cycle

The possibilities for strategic positioning for shipyards are by no means limited to the above examples. Any combination of elements which strengthens or provides new edges to the factors price, delivery time and quality on a long-term basis results in a new strategic position within a ship's life-cycle and linked cycles.

Peat Marwick states seven elements which determine long-term competitiveness. These are presented in Figure 5, in combination with relevant stages of ship's life-cycle. From Figure 5 (combined with the two previous figures) it can be concluded that there is a strong emphasis on design and production, thereby addressing mainly the position of the maritime technology prime contractor. There is also reference to the exploitation stage, but without specifying the role of the shipyard within the link with the transport and other similar cycles.

#### CASES

The Netherlands' shipbuilding industry,: short review.

The shipbuilding industry in the Netherlands reached its post WW-II top capacity at the end of

**the sixties, with** a workforce of about **50,000 em** played in shipbuilding only.

The downfall of the shipbuilding industry in West-Europe in the early seventies and the following restructuring has put an end to the building of ships above 20,000- 25,000 CGT in the Netherlands and reduced significantly the number and the total capacity of its shipyards.

Today the shipbuilding and ship repair industry consists of some 100 enterprises with a workforce of about 10,000, of which about 4,000 are involved in the building of sea-going ships. **Most shipyards are small- and medium size enterprises with the largest yards having a maximum capacity of about 20,000 CGT** per year. Yet, the total output of the shipbuilding industry in the Netherlands in the year 1992 amounted to more than 400,000 CGT. Such an output indicates a much larger workforce.

Shipyards in the Netherlands rely on a flexible infrastructure of subcontractors, colleague yards and manpower pools to temporarily increase their capacity. In addition, the industry has developed some unique concepts with respect to marketing and to facilitating enterprises for design and engineering, partial work preparation, parts fabrication, hull erection and outfitting.

Following the presentation on a ship's life-

cycle, and of the various possibilities to assume strategic market positions, a number of examples from the shipbuilding industry in the Netherlands are presented. The presentation has no advisory purpose, but mainly demonstrates the applicability of the strategic positioning of shipyards within a ship's life-cycle stages and within the link with other cycles.

#### Case 1: The Market Approach

This case addresses an approach, which has been remarkably successful over the past 25 years and which was developed by the Dutch Damen Group.

The approach is based on a business strategy focusing on world-wide marketing and selling of ships, with prime importance being given to work and industrial vessels of small and medium-size capacity (tugs, suppliers, fishery, vessels, etc.).

A strong world-wide operating marketing division evaluates future needs and defines principal technical and economical parameters for work and industrial vessels. Basic designs with modular standardized components, which enable a large variety of standard solutions in terms of propulsion, equipment and outfitting within standard hull forms are prepared. Following continuous and vigorous market assessments standard hulls and other equipment items are stocked whereas for some equipment and outfit items long term purchase contracts are made with preferential suppliers.

At this point the group links with the market on the basis of market prices and delivery schemes, usually outpacing the competition simply because of the advanced stage of a ship's completion at the time of decision by the future owner, and because of better purchase prices for hull, equipment, etc.

This unique concept does not only require a very effective marketing department, but also highly capable design and engineering, resourceful procurement, flexible production facilities for ship outfitting and commissioning and, above all, effective management at all levels of decision. Strong links with suppliers of technology and hardware are necessary; the absence of their own production facilities for hull construction is a striking feature of this Damen concept. An additional dimension to the strategic market position is provided by well organized after-sales services, which comprise the delivery of spare parts and services on a world-wide basis and at very short notice.

#### Case A The Product Technology Approach

This case addresses an approach which has been successful for over 25 years and which was developed by the Dutch IHC-group. The approach

is based on a business strategy focusing on the specialized technology of dredging and the world-wide market for floating dredging equipment for inland, coastal and seawaters.

This group covers the whole life-cycle of floating dredging equipment and links with the industrial column and with the exploitation cycle in several ways.

In the first place the group possesses a leading position in dredging technology research and development (MTI institute). This technology is put to use in several ways:

1. To develop and manufacture dredging equipment items such as pumps, drives, measuring and control systems, etc.;
2. To develop new dredging concepts; and
3. To incorporate equipment items and concepts with the building of new dredging vessels and with the upgrading of older vessels.

The link with the exploitation process consists of the delivery of spare parts, after-sales and other supporting services at the operational level. These activities are not only profitable, but also provide important information on the operational aspects of their equipment which can be used to develop new technologies and equipment items or improve existing ones.

Another element in this strategic concept is the market approach, more specifically the market-product combinations. The group has developed standard designs for a combination of dredging techniques, operational conditions and vessel capacities, of which the "Beavers" series is a well-known example. These dredges can be delivered at a very short notice as there is always a limited stock of partly completed vessels. All standard designs can be customized, i.e. they can be outfitted with various types and capacities of equipment.

Evidently the group also designs and builds unique dredges on a one-off basis, for well specified duties and operational conditions. In these designs too, standardized modular dredging components and systems are included. This enables to shorten delivery-times for spare parts and also to shorten repair times under operational conditions. In the dredging world, where material wearing is an accepted phenomenon these possibilities are of significant importance for the market position of the group.

#### Case 3: "One For All and All For One"; the Facilitating Approach.

This case addresses a unique concept which has been developed by the northern shipbuilders of the "Netherlands, in the provinces of Friesland and Groningen over the past 25 years. The concept is

based on the principle of facilitating enterprises.

This approach was thought up in the late sixties, with the introduction of numerical controlled (NC) flame cutting installations for steel plate materials. The advantages of this technology were easily recognized and appreciated, but the cost of investments in NC-equipment was beyond the financial possibilities of the northern shipyards (mostly small family enterprises). The solution was found by setting up a joint enterprise for steel parts fabrication under the appropriate name of Central Steel (CS). Central Steel used and still uses the latest state-of-the-art CAM-technology and delivers up to 100 steel packages per year, varying from simple inland ship forms to the most complicated forms of motor and sailing yachts.

Central Steel was shortly followed by a second centre of CAD/CAM excellence, under the appropriate name of Numeric Center. While CS concentrates on hull parts fabrication, i.e. cutting and bending of plate and rolled section materials Numeric Center carries out all preparatory activities for the fabrication of these parts, such as lofting, fairing, etc. Numerical data for NC-flame cutting is provided to CS but also directly to shipyards.

In the years to come an entire network of facilitating enterprises was founded around a holding structure, Central Industry Group (CIG) by setting up or taking over specialized firms. The network comprises firms for ship sales, marketing and design, engineering, manufacturing and installing of ship systems, ship equipment and outfitting, and recently shipyard development consultancy services.

A remarkable feat was the setting up of a special hull erection and outfitting yard by three Frisian shipyards, to overcome the limitation of vessel width imposed on many northern inland shipyards by the width of sluice gates, passage through bridges and others.

The network of facilitating enterprises covers the first three stages of a ship's life-cycle. The business strategy of CIG relies on advanced ship production technology (design, engineering, work preparation and hull parts fabrication) and on a very flexible infrastructure of facilitating enterprises. These enterprises also operate on markets outside the northern shipbuilding.

The long-term strategy of CIG is to improve ship production technology and expand its application through existing and new facilitating enterprises (piping systems, pre-outfitting, etc). The northern shipbuilders make effective use of this strategy which allows them to compete successfully in the market for series of custom-built ships and occasionally for highly specialized ships on a one-off basis.

## DISCUSSION

The cases presented above can now be discussed in relation with the models from the Strategic Positioning section.

Case 1 can not be easily positioned within Figure 2, as it involves standard designs (position 2) of mostly non-cargo vessels (position 1).

The strategic position within a ship's life-cycle is easily established within stages 1 (definition of needs) and 2 (product definition), as well as partially within stage 3 (production); see Figure 3. The strong links with the industrial column is evident (stages 2 and 3). However, the strategic position does not really correspond with the maritime technology prime contractor from Figure 4.

In a certain way the group does not contract the building of ships, but sells ships which, at the time of the final decision by the owner, are in an advanced stage of production. This unique approach addresses primarily the factors price and delivery time. The factor quality is evidently present in the form of product technology, of know-how regarding performance criteria and in the knowledge of price setting on the international market.

Case 2 can be positioned within Figure 2, as builder of innovative specialized non-cargo ships (position 1), but also as builder of standard ships of the same type (position 2). As it seems, the model from Figure 2 can not accommodate the combination of highly specialized Ships and standard designs.

The position within a ship's life-cycle can directly be recognised in position 3 from Figure 4. The technology-oriented group is usually involved in the stages definition production and exploitation and often in the first stage of a ship's life-cycle, definition of needs. This is the strongest and most versatile strategic market position and can be described as maritime technology prime contractor plus.

This position addresses all factors of competitiveness. The factor quality incorporates product and production technology, know-how regarding performance criteria, and the knowledge on price setting on the international market.

The third case is more complex, because it concerns two different groups:

1. CIG, a group of facilitating enterprises, and
2. The northern shipbuilders, a group of users of these enterprises.

The first group can not be positioned within Figure 2. The group does not build ships, but delivers technology and services through its facilitating enterprises. On the other hand the group can be positioned within a ship's life-cycle, in the stages

definition of needs and definition of product and in the link between the industrial column and the stages definition of product and production. This position addresses only the factor quality with respect to product technology, know-how regarding performance criteria and, to a certain limit, knowledge on price setting in the international market.

The northern shipbuilders can be positioned within Figure 2 in several ways. This depends on the input from the technology infrastructure of the first group. Several possibilities are listed below.

1. A possibility is the delivery of general cargo vessels (which corresponds with the lower part of position 2). The technology input from the facilitating network is not significant.
2. Another possibility is the delivery of relatively complex specialized cargo ships on a one-off basis (which corresponds with position 3). The technology input from the facilitating network is significant.
3. A third possibility is the occasionally delivery of steel hulls or blocks for other shipyards (which corresponds with position 4). The technology input from the facilitating network is limited.

The position of the northern shipbuilders within a ship's life-cycle corresponds with position 1 from Figure 4. This position addresses mainly the factors price and delivery time, whereas the factor quality is related mainly to production technology.

Following the above it can be concluded that the northern shipbuilders are highly flexible enterprises which assume different strategic market positions and overall production output capacities by varying their use of the network of facilitating enterprises.

In this concept all enterprises carry out core business activities only, hereby limiting the risks of unemployment in specialized disciplines. The success of this concept depends clearly on the organization and the management of joint projects on the basis of co-makership.

## CONCLUSIONS

The purpose of this paper is not to advise on choices regarding strategic market positioning, but merely to present solutions to competitiveness which emerged within the shipbuilding industry in the Netherlands over the past 20-25 years.

These solutions emerged in a period of downfall of the shipbuilding industry in West Europe, which resulted in a significant reduction of shipbuilding capacity. The shipbuilding industry in the Netherlands was no exception in matters of yard closures and the loss of jobs and of expertise. The building of ships above 20,000-25,000 CGT was ended and the industry had to find new markets and

new solutions to achieve and maintain competitiveness in a market which often appeared to be distorted by government subsidies.

It can not be proven nor is it claimed that the Dutch solutions, which emerged, were carefully designed, engineered and implemented. The claim is on creativity, unconventional thinking and a good measure of undertaking by companies and people who are totally devoted to their profession.

The models presented are simple but useful for understanding the available options and for explaining the position taken by the various cases within the shipbuilding market. A few conclusions can be drawn.

1. The shipbuilding industry in the Netherlands is strongly technology oriented and will be capable of maintaining its competitive position as long as it can innovate and maintain a high level of maritime technology which can be incorporated in the kind of ships it builds.
2. The factors price, delivery time and quality can be handled in different ways to obtain the best possible combinations with respect to the market and to the abilities of a shipyard. If a yard limits itself to only one factor, it could be placed in a vulnerable position.
3. The construction of the ship hull is not necessarily linked to the role of the shipyard as prime contractor. Case 1 demonstrates clearly that hull building is not necessarily core business, whereas maritime technology clearly is.
4. Linking a ship's life-cycle with other cycles provides market opportunities for shipyards, when they are recognized as such.
5. The concept of facilitating enterprises offers possibilities to preserve a high level of maritime technology (product, production, etc.) and of flexible production capacity, without the risk of over capacity and unemployment. This concept, however, requires a high level of communicative skills which involves so much more than just speaking the same language.

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Automated Blasting and Recovery of Coatings  
Removed From Ship Hulls  
Gary K Sweet (M), Sandroid Systems, Inc., U.S.A.

ABSTRACT

The environment and open air blasting are in conflict today. An economical coating removal system which recaptures the blast media, debris and dust at the substrate and recycles for reuse is now available.

The current method of hull blast cleaning is open blasting. This creates major air and water pollution problems from abrasive residue as well as paint and anti-foulant residues. Most drydock areas are not conducive to abrasive recovery and recycling; therefore, the abrasive residue falls into the drydock where it contaminates equipment, interferes with movement of equipment and is a potential health hazard to unprotected workers. There is considerable cost involved in clean-up and disposal of the spent abrasive and, if it is contaminated with hazardous paints, the spent abrasive must be disposed of as 'hazardous waste'. Disposal costs of hazardous waste can run as high as \$550 per metric ton (\$500 per short ton), greatly increasing the cost of blast cleaning.

With a properly designed containment system, the adverse environmental impact of blast cleaning can be essentially eliminated. The containment device should be flexible enough to conform to the configuration of the ship hull and allow the blaster to work unimpeded. Incorporated in the containment system should be an abrasive

recovery and recycling system to collect and clean the spent abrasive and then return the reusable abrasive to the blast cleaning operation.

The containment system would eliminate the air pollution problems and maintain a clean environment at the job site. Reclaiming and recycling spent abrasive would allow the use of recyclable abrasive that will reduce hazardous waste disposal costs and provide additional savings in material handling costs or abrasive movement and clean-up.

This abstract introduces a revolutionary flexible abrasive blasting and recovery containment system which permits the use of recyclable abrasive and prevents air and water pollution.

## INTRODUCTION

The current method of hull blast cleaning is open blasting. This creates major air and water pollution problems from abrasive residue as well as paint and anti-foulant residues. Most drydock areas are not conducive to abrasive recovery and recycling; therefore, the abrasive residue falls into the drydock where it contaminates equipment, interferes with movement of equipment and is a potential health hazard to unprotected workers. There is considerable cost involved in clean-up and disposal of the spent abrasive, and if it is contaminated with hazardous paints, the spent abrasive must be disposed of as hazardous waste. Disposal costs of hazardous wastes can run as high as \$550 per metric ton, greatly increasing the cost of blast cleaning.

Recently passed Federal regulations and many new state mandates make it necessary for the surface preparation contractor to devise a means of recovering those undesirable after-products which have been labeled as hazardous.

The problems associated with containment are well known: major increases in operating costs for erection and movement of a containment structure; devising a collection system; and the increased strain on workers due to the more confined, hostile environment, as well as use of protective clothing. Additionally, the design of the containment must be carefully engineered, lest there be damage to the ship, with the attendant liability risk.

With a properly designed containment system, the adverse environmental impact of blast cleaning can essentially be eliminated. The containment device must be flexible enough to conform to the configuration of a ship's hull and allow a blaster to work unimpeded. Incorporated in the containment system

should be an abrasive recovery and recycling system to collect the spent abrasive. The abrasive should be cleaned and returned to the blast cleaning operation.

A containment system eliminates the air pollution problems and maintains a clean environment at the job site. Reclaiming and recycling abrasive allows the use of recyclable abrasive which reduces hazardous waste disposal costs by about 99.5%. There are additional savings in material handling costs in abrasive movement and clean-up.

When properly effected, containment requires substantial capital investment in the design and fabrication of the containment structure, and the ventilation and collection equipment, to meet appropriate EPA standards. Since containment increases operating costs, one might view this capital expenditure as an investment that has a negative return.

Such a situation gives impetus to an engineering method of stripping that meets the environmental concerns, but at the same time is operationally cost effective, with an appropriate return on any capital investment that is required.

## ROBOTIC BLASTING SYSTEM

A multi-process, severe environment, ecologically safe, computer-controlled robotic blaster is now being manufactured. Accompanying the robotic blaster are completely integrated support trailers that provide abrasive grit blasting, both wet and dry, high-pressure water jetting, and electrical power for continuous operation.

The robotic blaster is mobile and equipped with a robotic controller having a modular open architecture microprocessor-



based computer that uses a hierarchical control scheme. Self-diagnostic capabilities, the modular arrangement and use of standard components enhance maintainability.

The robotic blaster is equipped with a vacuum recovery and reclassification system that source recovers and recycles after-blast material of abrasive grit and water blast procedures to meet or exceed local environmental protection guidelines by virtually eliminating fugitive emissions, drydock floor contaminants and reducing burden on landfills.

SEE FIGURE(S) 1,2, & 3

#### Process Capability

Automatic programmable control process paths, with the ability to work within 20 cmm (8 inches) of edges, comers and protrusions. “ The ability to operate, over flat or curved surface areas with a minimum radius of 90 cmm (3 feet). Blasts a minimum of 45 square meters (500 square feet) of ship hull surface area per hour. Accommodates different end effecters (dry abrasive blasting, water blasting and painting).

#### Recovery and Reclassification System

Recovers virtually all abrasive cleaning material and the airborne particles that are a result of abrasive blasting. Recovers, classifies, and cleans reusable abrasive material and discharges surface residue into an appropriate container for disposal on a continuous basis.

Reclaims up to 95% of the abrasive media for reuse, depending on the condition of the surface being prepared.

Recovers virtually 100% of water blast after-blast products.

#### Computer System Operations

Controls the robotic blaster operations from a computer control console.

Monitors the equipment functions while the system is in operation.

Operates the robotic blaster operations in three modes; Manual, Teach and Automatic.

Emergency Stop button overrides all system operations and immediately shuts down the blaster in an orderly fashion.

Collision sensing devices interrupt system for the protection of hardware.

End effector sensors track surface contours, automatically adjusting distance and pose of end effecters to obtain optimum performance.

#### Justification

Meets local environmental protection requirements for air and water quality in the coating removal process. Reduces burdens on landfills.

Reduces personnel exposure to the hazardous abrasive blasting work environment.

Reduces man-hours and increases productivity in surface preparation. High productivity is possible since the blaster is operational three (3)

## SANDROID WITH GRIT PROCESS TRAILER

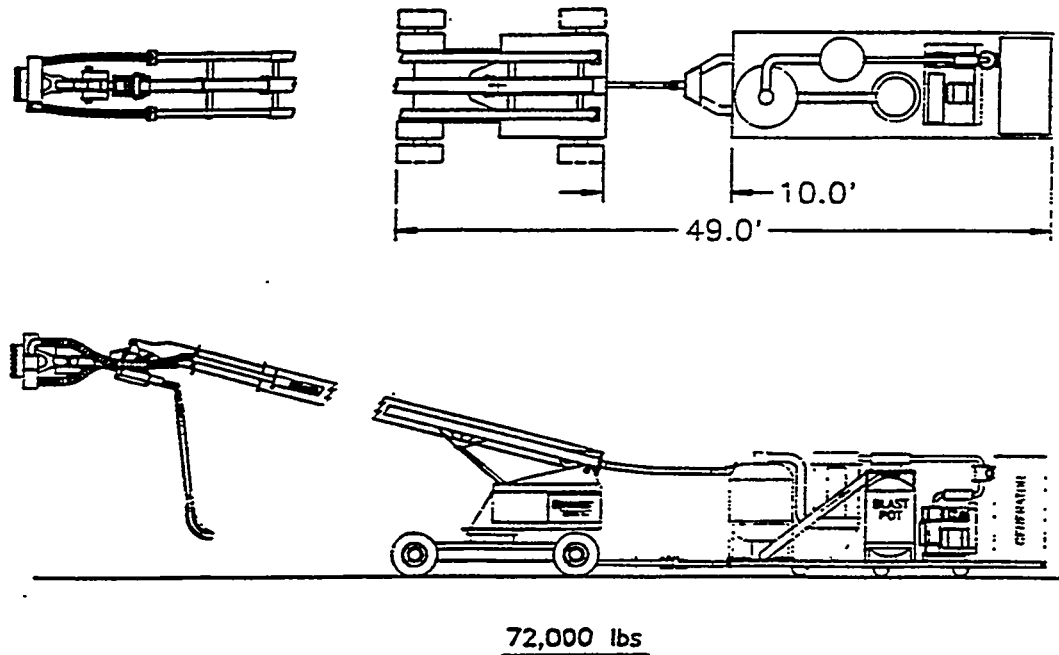
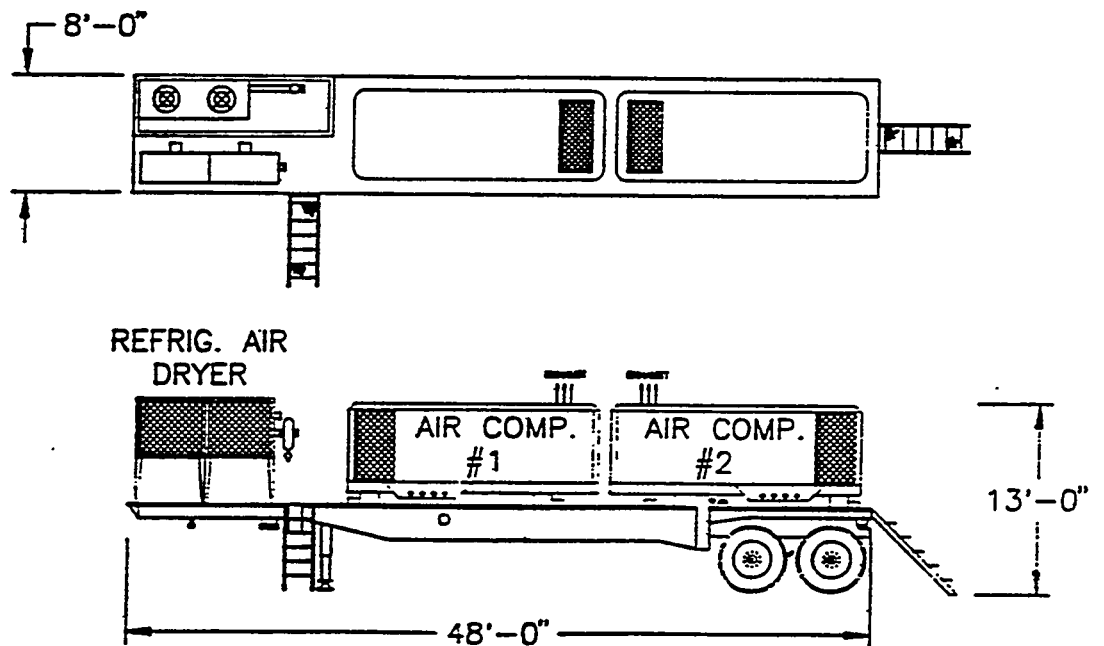


Figure 1

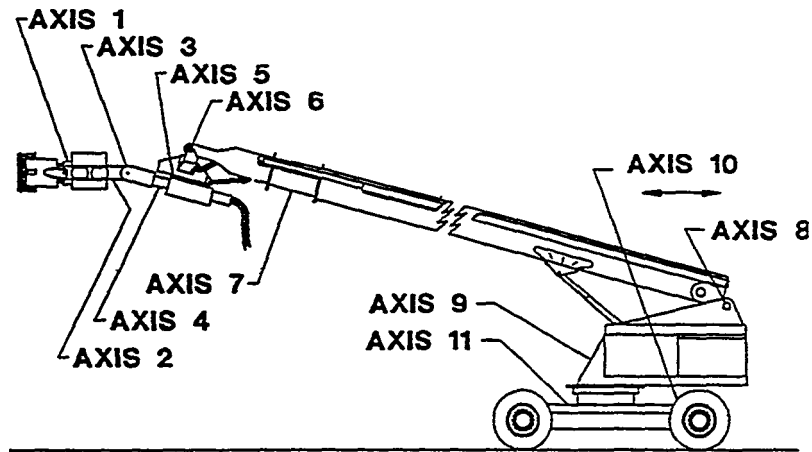
## AIR PROCESS TRAILER



58,700 lbs

Figure 2

# CONTROL AXES



- Axis 1 -100 Degrees of Movement
- Axis 2 -100 Degrees of Movement
- Axis 3 -180 Degrees of Movement
- Axis 4 -360 Degrees of Rotation
- Axis 5 -280 Degrees of Rotation
- Axis 6 -110 Degrees of Movement
- Axis 7 - Boom Extension
- Axis 8 - Boom Lift
- Axis 9 - Boom Rotation
- Axis 10- Forward And Reverse
- Axis 11- Steer Left and Right

Figure 3

- shifts per day.
- 1 A minimum crew of three (3) people can operate and control the entire robotic operation.
- 1 Scaffolds, tenting and aerial lift platforms required for abrasive blasting and surface preparation work are reduced or eliminated.
- 1 Dramatically reduces worker compensation and other employee fringe costs.

#### Control Axes

The robotic blaster has eleven (11 ) axes of control to position the blast nozzles and vacuum recovery head. All axes can be controlled by the operator in the Manual and Teach Modes of operation. In the Automatic Mode, nine (9) of the axes move in unison to the pre-programmed coordinates of the surface area.

#### Vacuum Principles

The patented vacuum recovery head is able to maintain a constant fluid seal on a ship hull surface area by controlling the volume of air introduced into the recovery head, and the displacement of air, abrasive, and surface blast residue from the recovery head through the outlets.

Air is injected at a determined volume into air casters to each of the seal elements that make up the flexible outer rim of the recovery head. Air and abrasive is forced through the blast nozzles at a constant rate, regulated by metering control devices on the blast pot.

A vacuum system provides the required air suction to collect the air, abrasive and surface blast residue from the head and transport them through an abrasive recovery and reclassification

system for collection, cleaning, storage and disposal.

SEE FIGURE(S) 4 & 5

#### Surface Types

The vacuum head lowers on a cushion of air that provides for a smooth flowoverflat, convex, and concave surface areas on a ship's hull. The vacuum head is capable of maintaining a seal with a minimum radius of three feet.

Sensors on the vacuum head send signals to the controller for needed seal element adjustments to follow the contour of the ship surface. The computer, in turn makes adjustments for the pitch, roll, yaw and stand-off distance of the end effector.

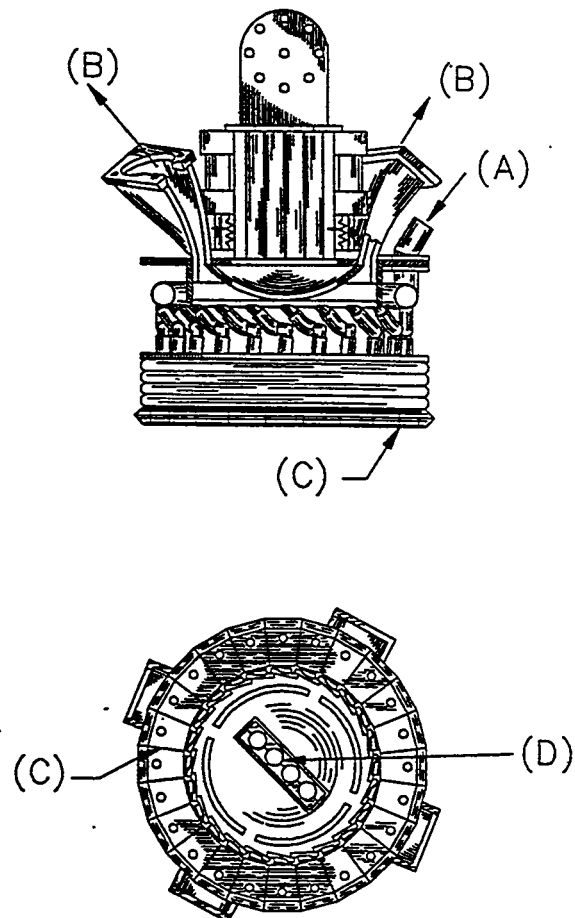
The design ensures the full recovery of abrasive and blast residue. Dry Abrasive Blasting

Surface preparation is accomplished with a specially designed venturi-style supersonic nozzle at high pressure ratings, and four times higher volumes of abrasive than is normally found in manual blasting operations.

The system uses end effector technology to direct the media particles to achieve a uniform particle distribution within the blast pattern. Control of the overlap from sparsely distributed particles in fringe areas maintains the uniform particle distribution from one pass to the next.

The air and abrasive are channeled through hose assemblies that are placed in the articulator's exoskeletal structure. The hose assemblies eliminate leaking couplings, screw punctures, washer wear and many of the other field maintenance problems of traditional abrasive hose equipment that results in down-time.

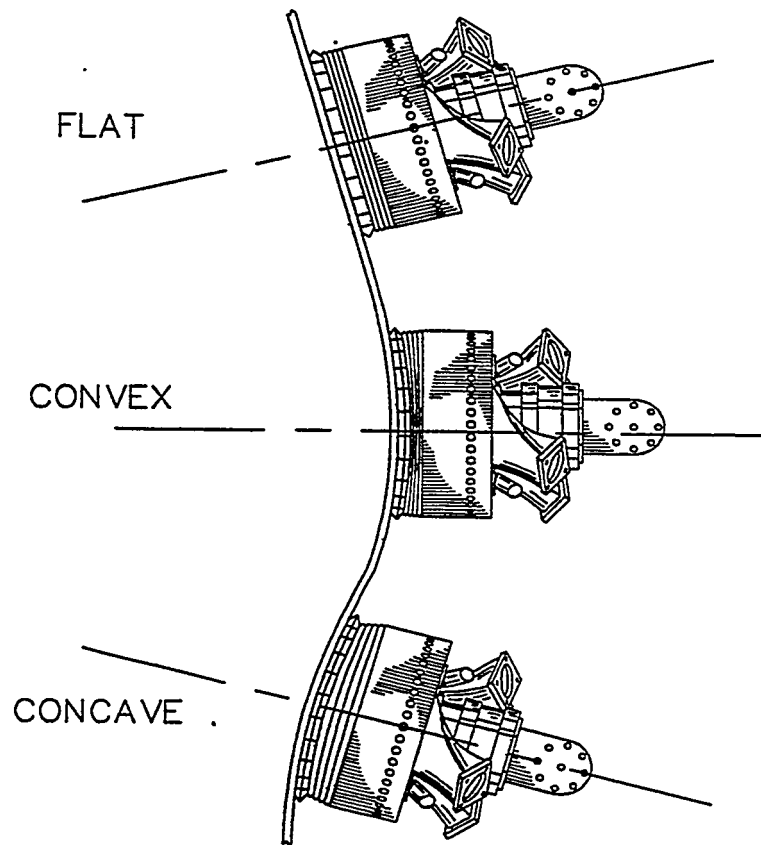
## VACUUM RECOVERY HEAD



- (A) Air introduced into recovery head
- (B) Blast residue exits through torreds
- (C) Seal elements on Outer Rim
- (D) Blast Nozzles

Figure 4

## VACUUM RECOVERY HEAD (VRH)



The VRH glides on a cushion of air that provides for a smooth flow over flat, convex or concave surface areas

Figure 5

## Abrasive Recovery and Reclassification System

A closed cycle vacuum recovery system removes residual surface material and reclaims after-blast products in both abrasive grit blasting and in water blasting processes. The abrasive recovery and reclassification system is comprised of components to perform recovery, grit and debris separation, blast media reclassification, “grit washing” and recycling on a continual basis.

The system reduces costs and increases productivity. This is achieved through the engineering design to:

- 1 Recover and process dry abrasive material for reuse, recovery and containerization of surface coating residue in a continuous process.
- 1 Reclaim up to 95% of the dry abrasive media for reuse, depending on the condition of the surface.  
Provide a dust free work environment and reduce personnel exposure in the handling of hazardous abrasive blasting material.  
Meet the local environmental protection requirements while blasting and performing other surface preparation of ship hulls.
- 1 Recover and collect water blast, water and residue for recycling.

## Abrasive Blast Pot Equipment

The abrasive handling equipment consists of a blast pot unit, blast nozzles and blast hose assemblies. The blast pot unit is computer controlled to allow working pressure and air/media mixture to be precisely regulated.

The blast pot unit is design with double chambers to permit automatic or manual filling for continuous uninterrupted operation; an ASME coded tank certified for 125 psi maximum operation pressure; an access man-way; a bottom clean-out plug; six 5 cmm (2 inch) bottom outlets and remote control choke and metering controls.

## Blast Nozzle End Effecters

The venturi style blast nozzle is designed for high production; the nozzle is manufactured with an extended wear liner, providing abrasion wear resistance. Water blast nozzles are available for operation with water blast pumps of 10,000 psi and 30,000 psi processes.

## Blast Hose Assemblies

The blast hoses use 4-ply” static dissipating hose, structurally bonded to a nozzle holder using a reusable, unbreakable copolymer coupling assembly. The design features of the blast hose assemblies result in less field maintenance and therefore increased productivity.

## Recovery and Reclassification Equipment

The system is capable of recovering and processing material resulting from abrasive blast and water blast processes in a continuous system.

Reusable abrasive, from dry abrasive blasting, is separated from the removed coatings chips and abrasive fines. Recovered abrasive media is “washed” in an air aspirator and then returned to the **blast pot on a continuing basis.**

Fines and coating particles are separated and transferred into environmentally approved waste disposal containers.

The recovery and reclassification equipment consists of:

- 1 Vacuum system
- 1 Vacuum recovery head
- 1 Cyclone separators and classifiers that separate abrasive media from airborne particles and material fines.
- 1 Fitter units that filter the fines from the return air; collect and transfer the fines to waste disposal containers on a continuous basis.
- 1 Multi-Aspirators to clean the recovered abrasive media for reuse.

## HOSTILE ENVIRONMENT PROTECTION SYSTEM

The system is designed to work in hostile environment job-site applications and engineered for the protection of vital components. Although designed specifically for abrasive blasting applications, this package works for all airborne particulate contaminants found in a shipyard.

### Design Features

- 1 Boom wiper seals create a close bond and a snug fit by sealing the open areas between boom sections.
- 1 Chrome plated telescopic cylinder rod is for longer life; this manufacturing process acts as a barrier to cylinder rod contaminants.
- 1 Electronic equipment and computer boards are housed in waterproof,

temperature controlled compartments. Electronic boards easily slide out

The Sandroid hostile environment protection results in extended equipment life and reduced downtime, thus ensuring greater productivity.

## SUMMARY

A standard byproduct of most sand-blasting operations is a large cloud of dust. Spent abrasive and the removed coating litter the work area and often must be handled as hazardous waste. A system that collects its own spent grit and blast debris saves money, time and the environment.

The "Robotic Blaster" from Sandroid Systems, Inc. does that and a whole lot more. its blast head conforms to both flat surfaces and curved surfaces with a minimum radius of three feet. It includes the air-and abrasive- delivery system, as well as a vacuum-recovery system to collect blast residue. When blasting ship hulls, the robot covers a minimum of 500 sq ft per hour.

The blasting head operates at the end of a telescoping boom and manipulator assembly with a reach of 90 ft. A total of eleven axes permit positioning the head against virtually any surface within its reach. Integrated support trailers carry the air compressors, dryers, generator, the grit-handling apparatus, and the residue-reclassification system.

All phases of blaster operation are under computer control. One or more resolvers at each axis report axis positions



which are displayed on the operator console. Sensors in the vacuum-recovery head read the contour of the work surface, permitting the computer to maintain the optimum distance and angle to the work surface. The computer regulates working pressure and air/media mixture as well as the two pump hydraulic system. 'It constantly checks for errors or out-of-tolerance operation and shuts down the system if it detects problems.'

Two modes of control are available. In the manual mode, the operator maneuvers each axis through toggle switches on the control console. Once the head is about 18 inches away from the work surface, the operator switches to joystick/robotic control. For this method, the operator controls direction and speed with the joystick. The robotic control adjusts the axes to maintain the pose and stand-off distance of the end effector.

In automatic, the operator defines a

work-window size (width and height). Next the operator moves the end effector to about 18 inches from the work surface. Computers then maneuver the blasting head over the work area within eight inches of edges, comers, and projections. Collision sensors interrupt the system to protect the hardware. End effector sensors track surface contours and adjust stand-off distance and pose for optimum performance. An emergency stop button overrides all system operations to shut the blaster down in an orderly fashion.

After recovering its grit and the debris removed from the work surface, the reclassification system sorts and cleans abrasive, recovering as much as 95% of it for reuse. In addition, the system separates the surface residue and discharges it into appropriate disposal containers. The systems uses different end effecters for high pressure water blasting and painting.



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## Navy High-Pressure Waterjet Closed-Loop Paint Stripping System

John Williams (V'), Naval Surface Warfare Center Carderock Division, U.S.A., and Robert M. Rice (V), United Technologies, Pratt & Whitney Waterjet Systems, Inc. U.S.A.

### ABSTRACT

The marine refurbishment industry currently utilizes abrasive blasting for hull coatings removal. These processes generate extreme amounts of waste material, which must be contained and disposed of properly. The cost of containment the hazardous work environment and the amounts of hazardous waste produced are all significant disadvantages of the existing processes. Additionally, environmental regulations and safety standards are being introduced which demand new techniques for marine coatings removal.

In light of these factors, the U.S. Navy's Naval Surface Warfare Center - Carderock Division entered into a joint initiative with the U.S. Air Force to introduce an alternate paint and marine growth removal method, including complete effluent recovery at the source. This system, using only high pressure water, is semi-automatic and mobile. The system can operate independently in a dry-dock without external utilities. In the end, the system will eliminate the current problems associated with coatings removal and reduce the overall operational costs.

The contract for this work was awarded to Pratt & Whitney Waterjet Systems in June 1993. The work discussed is funded by the Navy under Air Force Contract F33615-91-C-5708.

### BACKGROUND

In today's demanding and competitive marine refurbishment industry, new technologies are needed to replace existing blasting methods (Figure 1).

These methods are either too costly to continue or being totally banned or restricted by environmental regulations such as the Federal Water Pollution Control Act and the Water Quality Act of 1987, the Clean Air Act and the Clean Air Act Amendments.

Marine refurbishment, however, presents complex technical challenges and environmental issues because of the unique work environment.

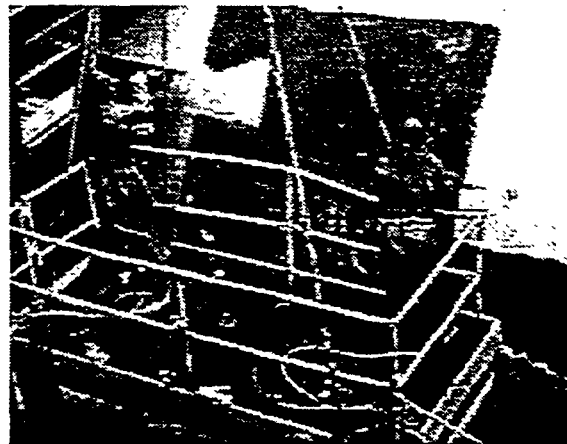


Figure 1 Typical Shipyard Hull Blasting

Environmental issues are working against the continued use of current grit and sand blasting technologies. These issues are primarily related to release into the air or water and disposal of the heavy metals used in marine coatings: copper, cadmium and lead.

The technical challenges are formidable in scale (encompassing both shipyard and drydock operations) and in effluent containment (where virtually 100% containment is the only acceptable standard). To this end, the USAF and USN have combined to produce a Waterjet Demonstration System for use in Naval and commercial shipyards.

The goal of this project is to integrate lab-demonstrated, custom-designed and off-the-shelf hardware into a prototype system to demonstrate complete removal and recovery of marine coatings. The project has been through design, fabrication, verification testing and demonstration phases, removing paints from active Navy ships. The prototype demonstration system is now being slated for production work on active Navy vessels. The system was designed as a dual-use system to provide as much benefit to the commercial shipbuilding industry as it will to the Navy.

## SYSTEM DESCRIPTION

The system (Figure 2) is totally mobile and self contained for drydock, shipyard or harbor operation. Basic system elements include a high-pressure water pump, a teleoperated transporter with a 5-axis telescoping arm, a 6-axis manipulator with specialized end effector, a recovery process trailer, and a system remote control console.

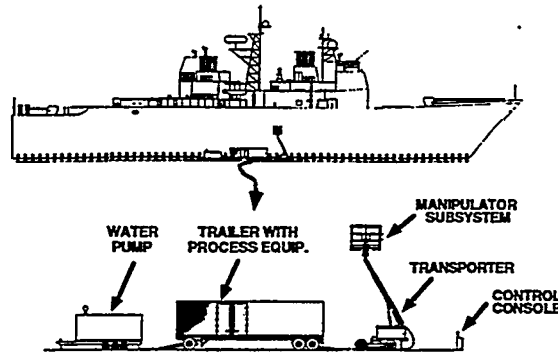


Figure 2 Coating Removal & Recovery System

The end effector incorporates a 6-inch-wide waterjet nozzle in a frame designed for precise application of the waterjet energy against the side of a ship. Stripping paths are mechanically guided by the frame. The end effector has the ability to "comply" with the various surface contour variations typically encountered on ship hulls. It also incorporates an effluent-containment shroud around the waterjet nozzle and a strong vacuum to completely contain all process water and coating residue and transfer them to the water reclamation unit.

For completely closed-loop operation, the system includes a modular water reclamation subsystem for water filtration and recirculation; the only waste product in waterjet processing is the removed coating and fouling. Finally, the entire system is completely mobile; it is transported on wheeled trailers.

### System Advantages

The waterjet process is inherently superior to conventional marine coating removal methods, such as grit blasting, shot peening, sanding, chipping, scraping or brushing; it offers the major advantages listed below:

- Paint is the only waste product,
- No dust or airborne contaminants,
- Requires no containment structures,
- Does not subject workers or the environment to hazardous waste,
- Very effective removal of surface contaminants such as salts, "

Ability to selectively strip layers of a coating or entire coating in one pass,  
Eliminates the need for respirators or masking of mechanical equipment  
Other operations can be performed in unison.  
Leaves surface clean and dry,  
Requires no cleanup after stripping,  
Lower manpower requirements and higher paint-removal rates,  
Allows repainting with no additional surface preparation, and  
Meets environmental concerns and has potential for large cost savings.

### Subsystem Specifications

The Navy Waterjet Demonstration System (Figure 3) consists of an end-effector subsystem (nozzle, effluent-recovery shroud, nozzle rotation drive, and controls), a high-pressure pump, an effluent-recovery and water reclamation system, a manipulator and transporter, all on compact mobile trailers for maneuverability in shipyard areas.

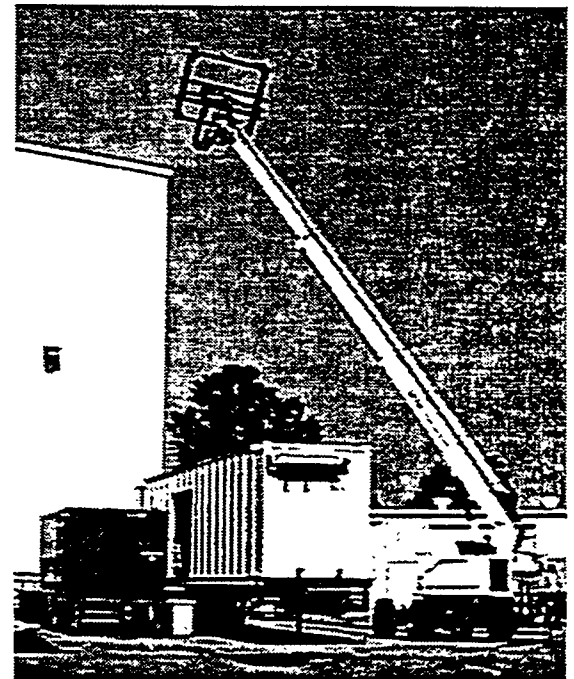


Figure 3 Mobile, Self-Contained System (11 Axes)

### End Effector Subsystem

The end effector subsystem (Figure 4) is a self-contained nozzle and shroud assembly with a hydraulically controlled, 15-cm (6-inch) wide stripping nozzle. Controls are included for nozzle standoff distance and compliance (mating to the

coated surface contour) for complete effluent capture.

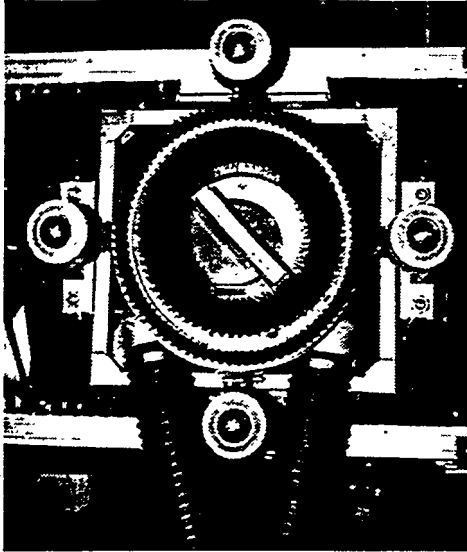


Figure 4 End Effector with Standoff Control Device

**Nozzle.** The Even-Energy™ nozzle contains more than 20 laser-drilled industrial-sapphires orifices, of varying sizes and placement; the sapphires provide long life, and the size and placement provide even energy distribution. The nozzle body does not wear out from water flow; the orifices in the nozzle body are the only consumables. Nozzle orifices are easily changed-out with a common Allen wrench and the nozzle body is easily removed with adjustable wrenches.

**Vacuum Recovery Shroud.** A unique vacuum recovery shroud designed to capture virtually 100% of the process water, the suspended paint particles and the fouling residue. The vacuum shroud quickly removes all effluent so as not to diminish the stripping efficiency of the nozzle as it progresses along a hull or other surface. As it removes the process effluent, it simultaneously dries the substrate, leaving a rust-free surface.

**Compliance and Standoff Control.** A mechanical device is built into the end effector frame to control standoff distance to ensure optimal surface contact and efficient effluent capture over large variations of curved surface contours.

**Hydraulic Drive.** The transporter's hydraulic power unit rotates the waterjet nozzle. It supplies hydraulic fluid to a motor in the end effector, which drives a high-pressure water swivel through a belt-and-pulley mechanism. Hydraulic power was selected over other chives because of its higher starting torque, accuracy and reliability.

## Manipulator Subsystem

The manipulator subsystem (Figure 5) provides the interface between the ship surface and the end effector, which moves back and forth across the manipulator's 1.37- x 1.98-m (4.5- by 6.5-foot) envelope at optimal standoff distance while maintaining contact so the vacuum recovery head can capture all effluents.

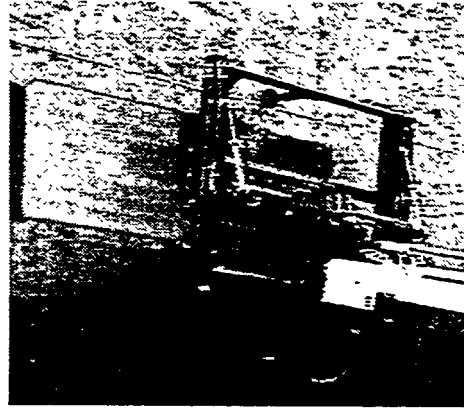


Figure 5 Manipulator and End Effector

## Transporter Subsystem

An off-the-shelf, mobile, telescoping transporter subsystem (Figure 6) accurately positions and repositions the manipulator against the ship, barge or other surface to be processed. The transporter is capable of reaching 18.3-m (60-feet) high with 360° continuous rotation. All process hoses and cables are routed along the boom.

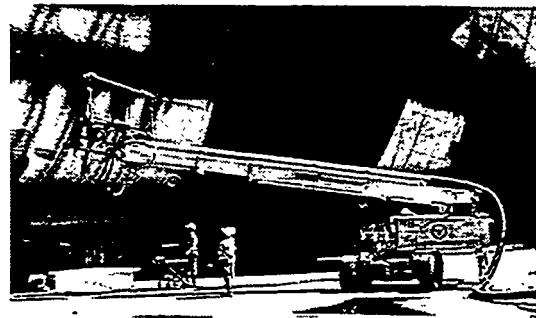


Figure 6 Transporter

**Remote Control Console.** A console (Figure 7) provides the operator a single point from which to control the transporter, manipulator, high-pressure pump and water reclamation unit. The console is mounted on a roll-around cart so it can be positioned for maximum operator convenience and visibility.

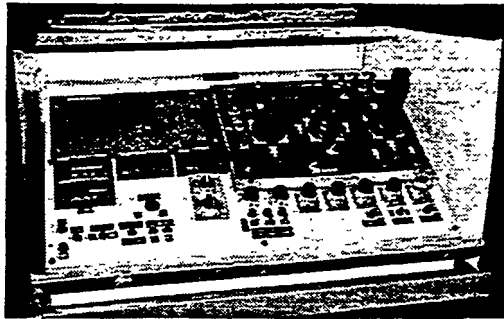


Figure 7 Remote Control Console

**Auxiliary Power Generator.** A separate power generator is provided on the transporter for operation of the manipulator and the remote control console.

### High-Pressure Pump Subsystem

A high-pressure, dual-intensifier, hydraulic water pump (Figure 8) is carried on a separate small trailer. The pump supplies water to the end effector at the required high pressure and volume for the stripping operation.



Figure 8 Mobile High-Pressure Water Pump

The pumping unit is self-contained, diesel-powered and ideally suited to the task of stripping thick tough coatings such as anti-foulant topcoat, marine growths, and epoxy primer. It is capable of supplying water to the end effector at up to 37.8 liters per minute (10 gpm) and 2482 bar (36,000 psi). All pressure hoses, tubing and fittings are burst rated at 6207 bar (90,000 psi).

The hydraulic system drives dual, plunger-type intensifiers as part of a closed-loop system. The intensifiers are designed for easy accessibility for maintenance and repair. The hydraulic system includes an integral full-flow filtration system, hydraulic reservoir and pressure gauges.

The operator controls the pump intensifier and pressure from the remote control console, which can be wheeled around the dock for best operator visibility. The pump can also be manually operated at a control panel on the pump face. An automatic protection feature monitors critical pump functions and warns the operator if abnormal parameters are detected.

### Effluent-Recovery Subsystem

The process water, paint and fouling residue are collected by the effluent-recovery system for filtering the paint and residue, removing leached ions (copper, cadmium, lead, etc.), microparticulates, chlorides, sulfates, nitrates and other contaminants picked up from the surface. This mobile subsystem is installed in a standard shipping container and chassis (Figure 9).



Figure 9 Pump and Recovery Subsystem Trailer

The effluent first enters the recovery system through a 6-inch vacuum recovery hose attached to the shroud around the nozzle. A dri-prime pump removes the material from the bottom chamber of the vacuum and deposits it into a vibratory **liquid/solid separator**. The separator acts as a "removing about 95% of the solid material". The liquid is then pumped to a micro-separator, which is the first stage of the water reclamation unit. The micro-separator uses centrifugal force to remove all material heavier than water. The water is then passed through a coalescing tank (to remove oils and film), then through an ozone generator, charcoal filter, micro-filters and, finally, a deionization system with conductivity meter to ensure that the water recycled to the pump is Grade A deionized water.

**Utility Trailer.** To provide system mobility in the limited space of shipyards and dry-docks, the effluent-recovery subsystem is installed in a standard shipping container, which is approximately 12.2-m long x 4.1-m tall x 2.4-m wide (40- x 13.6- x 8-ft). The container can be removed from the chassis and placed flat on the

drydock floor or supported at each corner by a dual-wheeled caster. The container can be moved on these casters with a forklift and towbar.

**Vacuum Unit.** A high-powered wet/dry vacuum unit (Figure 10) recovers nearly 100% of the process water as the coating is being removed. The liquid/solid slurry is captured in a removable hopper under the vacuum unit in the process trailer. The entrained air is filtered and exhausted to the atmosphere.

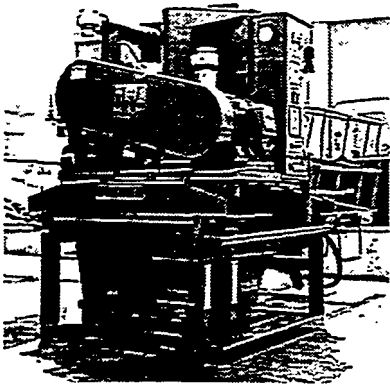


Figure 10 Vacuum Unit

**Sump Pump.** A dri-prime pump (Figure 11) removes the liquid/solid slurry from the vacuum collection hopper and pumps it to the liquid/solid separator. The pump is capable of handling liquid slurries with solids up to 3.8 cm (1.5 inch) in diameter.

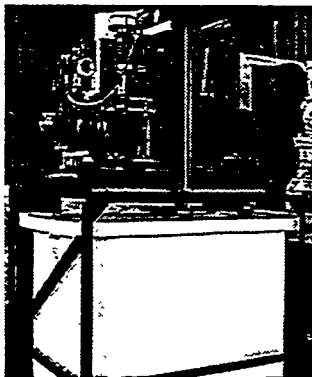


Figure 11 Sump Pump

**Liquid/Solid Separator.** Because of the large amount of solid waste material generated in stripping a large ship, a customized liquid/solid separator (Figure 12) is used as a preprocessor of the effluent before transfer to the water reclamation unit. An adjustable mesh vibrating screen separates the majority of the solids from the liquid. Those solids are dumped into a 208-liter

(55-gallon) drum for disposal. The remaining dirty water is captured in a collection tank before being pumped to the water reclamation unit for further filtering and water treatment.



Figure 12 Liquid/Solid Separator

**Water Reclamation Unit.** A modular water reclamation unit (Figure 13) filters and conditions the used process water and returns it to the high-pressure pump.

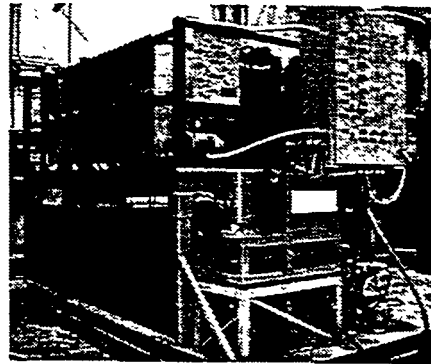


Figure 13 Water Reclamation Unit

The sump pump first directs the water to a centrifugal microseparator, which removes a majority of the particulate. The water from the centrifugal separator is then directed into a 1135-liter (300-gallon) raw water tank. The raw water is pumped through a series of filters, an oil separator, and an ozone generator before being deposited into a 757-liter (200-gallon) clearwell tank. The water in the clearwell tank is then passed through deionization tanks to remove heavy metals, then through a final 0.35 -micron filter for reuse by the system's high-pressure water pump. To compensate for evaporative losses, potable water is automatically added from the system's make-up tank.

**Generator.** A 125-KW diesel-powered electric generator (Figure 14) powers the vacuum unit, water reclamation unit, air compressor, dri-prime pump, liquid/solid separator and other trailer utilities.

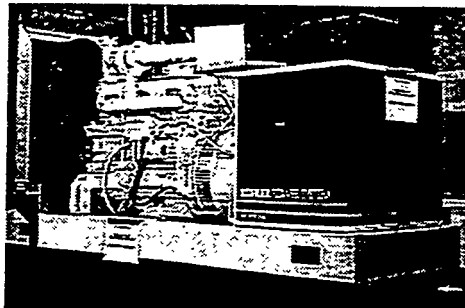


Figure 14 Diesel-Powered Electric Generator

**Air Compressor.** An electric-driven air compressor (Figure 15) supplies air for operation of the manipulator, pumps, valves and utility equipment.

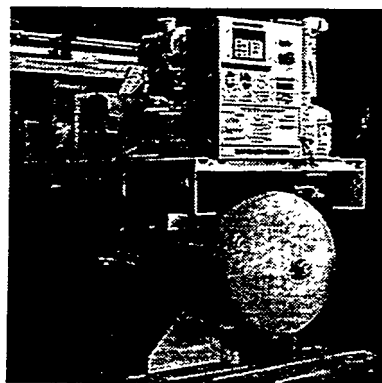


Figure 15 Air Compressor “

## PANEL TESTS

As part of the Navy Waterjet Demonstration System effort, 40 panels were tested to evaluate paint removal rates, remaining surface contaminants, and paint adhesion after waterjet processing. Specific areas of evaluation include:

- Tooth Profile...to assess waterjet effects and variation in removal rates from varying tooth profile,
- Paint thickness...to evaluate effects of paint thickness on removal rates,
- Removal Quality . . .to assess how various percentages of paint left on the surface after stripping affect paint adhesion, and
- Adverse Effects..to determine any adverse effects of waterjet processing from salt-fog and pull-adhesion tests.

## SHIPYARD TEST AND DEMONSTRATION

The system was moved to Puget Sound Naval Shipyard on 18 July 1994. Its first test at the yard was the removal of about 46.5 m<sup>2</sup> (500 ft<sup>2</sup>) of underwater hull paint from the USS NIMITZ (CVN 68). During test, test, (Figures 16 and 17) the system showed its capability to remove all of the paint to bare metal and selectively strip layers of paint from the surface. The amount of material removed in selective stripping ranged from the first layer of antifoulant to the first layer of anticorrosive. This was performed by varying the water pressure and nozzle speed across the ship's hull.

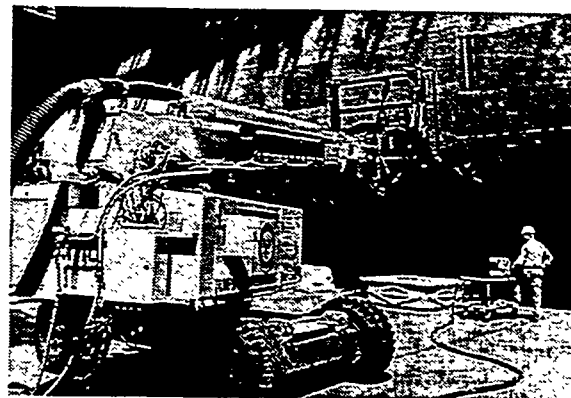


Figure 16 Stripping USS NIMITZ



Figure 17 Manipulator on NIMITZ Hull

The coating system on the NIMITZ underwater hull consisted of two coats of International FP Series anticorrosive paint and four coats of BRA Series antifoulant paint. The coating had been on for less than 4 years, averaged 30-40 mils thick and was in excellent shape. The ship was sent back out with the paint system intact except in the areas where the tests were performed and anew coating was applied.

The removal rate achieved was 12.6 m<sup>2</sup>/hour (136 ft<sup>2</sup>/hour). This is only the time required to remove the paint from the 1.37- x 1.98-m (4.5-by 6.5-foot) work envelope, not the time to move the manipulator frame from spot to spot, which takes only a few minutes.

The vacuum recovery shroud on the system performed well; after some minor adjustments were made, it achieved 100% effluent recovery. After the paint was removed, the bare metal did not flash rust. This is because of the strong vacuum and the -60 C (-140 F) heat of the water, which speeds evaporation and eliminates the potential for surface flash rusting.

The water and effluent were tested for trace metals as it entered and left the effluent recovery system. The measured values are listed in Table I.

<u>Metal</u>	<u>Effluent Recvcd</u>	
	<u>(mg/L)</u>	<u>Water (mg/L)</u>
Zinc	13.2	<0.10
Lead	<0.10	<0.10
Barium	17.3	0.14
Arsenic	0.10	<0.10
Selenium	0.20	<0.10
Copper	19.7	0.11
Silver	<0.10	<0.10
Cadmium	<0.10	<0.10
Nickel	0.39	<0.10
Chromium	0.39	<0.10

Table I Analysis of Effluent

Most of the paint residue is pulled out by the liquid/solid separator and deposited into a 208-liter (55-gallon) drum (Figure 18). This waste was also analyzed, and results are listed in Table II.



Figure 18 Solid Waste Collected

<u>Metal</u>	<u>Qty</u> <u>(mg/kg)</u>
Zinc	2700
Lead	217
Barium	1950
Arsenic	<20
Selenium	<20
Copper	296,000
Silver	<20
Cadmium	<20
Nickel	329
chromium	234

\*Method: EPA 3050A & 6010A

Analysis Dates: 26&29 Sep 94

Table II Analysis of Solid Waste

The next test was removal of non-skid coating from the flight deck of the NIMITZ (Figures 19 and 20). Data was not collected on the coating thickness, but the entire coating system was removed at a rate of 19 m<sup>2</sup>/hour (205 ft<sup>2</sup>/hour).

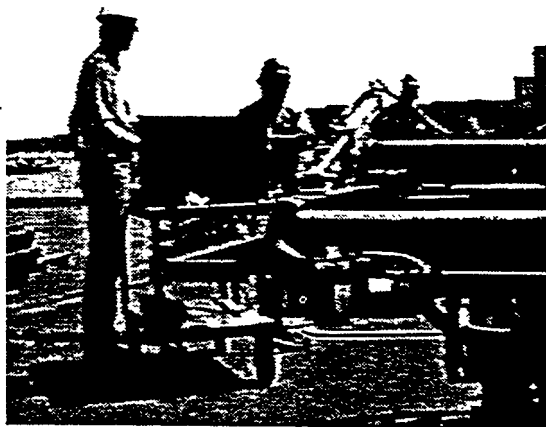


Figure 19 Setting Up for Deck Stripping

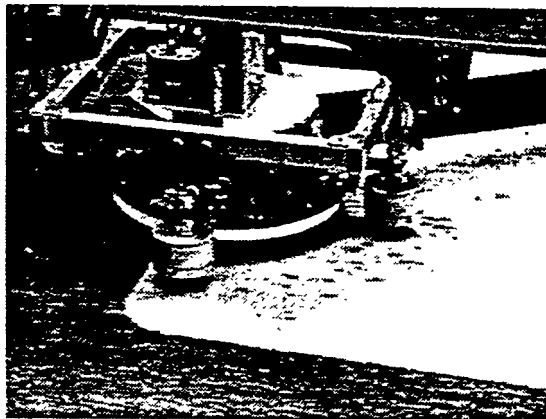


Figure 20 Stripping Non-Skid Deck Surface



The system was then moved to Drydock 1 at Puget Sound to begin testing on the USS STURGEON (SSN 637). Several thousand square meters (feet) were stripped, demonstrating both selective stripping and complete stripping to bare metal.

It appears that the STURGEON had a 4 or 5 coat system, but both the number of coats and the total thickness varied due to many touchups. The paint system was in fair condition and came off faster than in the NIMITZ testing a removal rate **of about 16.7 m<sup>2</sup>/hour (180 ft<sup>2</sup>/hour) was achieved** on the STURGEON (Figures 21 and 22).

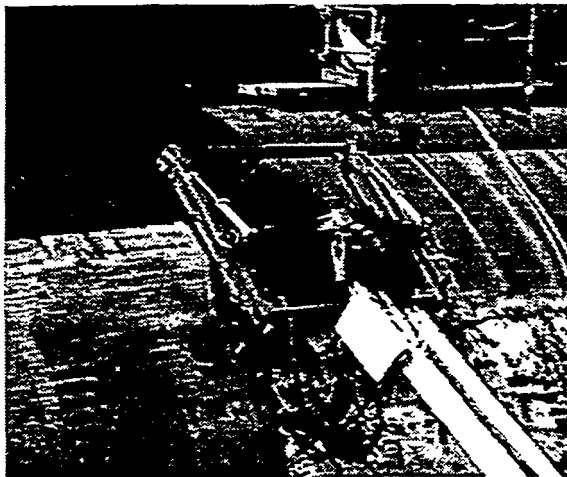


Figure 21 Stripping the USS STURGEON

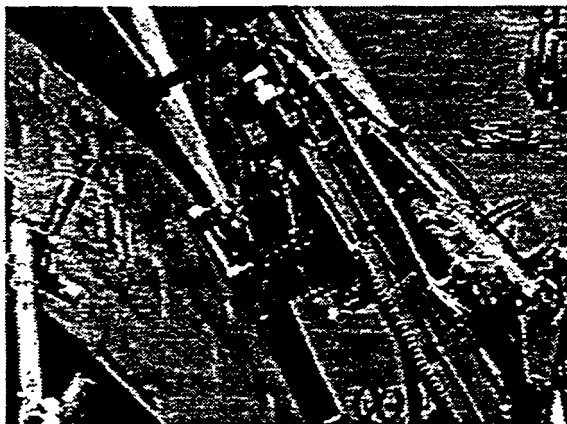


Figure 22 Side View of STURGEON

The surface was tested after paint removal to quantify the amount of chlorides remaining on the substrate. The Bressle Method Test Kit and Swab Kit were used and, in all tests, the readings were **from 0 to 2 µg/cm<sup>2</sup>. The vacuum recovery head** performed well, and areas that were stripped to bare metal did not rust for 9 days, until a rainstorm

washed the salts down from the unstripped areas above.

On 20 October, the system was shipped to Pearl Harbor Naval Shipyard (PHNSY) to remove **2322.5 m<sup>2</sup> (25,000 ft<sup>2</sup>) of freeboard paint from the** USS Leftwich (DD 984). Since the Leftwich had organotin on the underwater hull, dry abrasive blasting or open water blasting was not permitted on the freeboard until all the organotin was removed and the drydock was thoroughly cleaned. This sequential process would lengthen the LEFTWICH's time in drydock, so PHNSY requested the use of the Navy Waterjet Demonstration System to see if it could remove both coatings simultaneously and reduce the ship's time in drydock.

The freeboard of the LEFTWICH had a 2-year-old coating system in excellent condition, consisting of 5-coats: one coat of Cathacote 302 Zinc-Rich Epoxy, one coat of MIL-P-24441 Formula 154 Epoxy, and three coats of TT-P-490 Haze-Gray Enamel.

This was the first "production" test of the Waterjet Demonstration System, and it performed well, removing the 5-coat system at a rate of **19 m<sup>2</sup>/hour (205 ft<sup>2</sup>/hour).**

The Leftwich work provided the project team with valuable information that is being incorporated into the second-generation, production version of the system. The work at PHNSY will continue through January 1995. The equipment will then be moved to Long Beach Naval Shipyard for further prototype testing on the USS FOSTER (DD 964).

## CONCLUSION

The prototype system is performing better than expected for a technology-demonstration unit. Design work is already proceeding on a production version of the mobile waterjet stripping system.

Ongoing work with the prototype and production systems will be closely monitored and detailed information will be collected on mean time between failure (MTBF), operating costs, cost savings, maintenance schedules, surface conditions, production removal rates, paint adhesion, and overall success of the system.



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## Analys Analysis of Competitiveness in Commercial

### Shipbuilding

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Van Hoist & Koppies, The Netherlands

#### ABSTRACT

The paper consists of two elements i.e.:

- the analysis of the competitiveness of the Dutch shipbuilding industry, and
- the structural and organizational changes in the Dutch shipyards since 1983, based on market approach and cost reduction.

The objective of a study completed in 1993 was to gain insight into the competitive position of the Dutch shipbuilding industry for seagoing merchant ships. Different indicators were developed and analyzed for the period 1984-1992. Labor cost and exchange rates are the two parameters which enable the assessment of the development of the labor cost, which is calculated in US\$ per cgt. For selected countries the level of productivity (and thereby the labor cost per cgt<sup>1</sup>) has been adjusted to an estimated degree of subcontracting. The Netherlands shipbuilding industry shows an average share in the AWES<sup>2</sup> production of about 8-9 percent in the period 1984-1992. This indicates that a

competitive position has been maintained. Some Asian countries and Poland show a lower level of labor cost per cgt than The Netherlands.

The changes in structure and organization of the Dutch shipbuilding industry, which concentrates mainly on niche-markets and special types of vessels, is discussed. The niche-market approach has been leading to product specialization at several yards. The expectations for the shipbuilding market in Western Europe are discussed briefly.

#### INTRODUCTION

The international competitive position of the shipbuilding industry in the Netherlands got the attention of shipbuilders and administrations as soon as Dutch shipowners started to place orders in Japan (late '60s - early 70s). Delegations of shipbuilding experts visited Japan to study building methods, organization and lay-out of shipyards, and the construction of ships.

The findings of the delegations confirmed that low labor cost were not the only factor for the success of the Japanese builders; but that these were combined with high productivity, which was the result of an analytical approach of the production process. Production friendly and simple designs of details, well organized production systems, clean shipyards, building methods which were reducing lead times, and many small, apparently not important, organizational details were noticed and explained the differences in cost. The findings showed the upcoming changes in the industrial climate.

In the same period the North-Sea was developed as an oil and gas producing area. The industry was booming and the economy growing as labor productivity increased. Some shipyards concentrated on this industry and floating and fixed platforms were built. This regional market was a matter of competition between regional builders from North-West Europe. However, the shipyards which were active in the international market, meeting Japanese competition,

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<sup>1</sup> A common measurement of production of the shipbuilding industry is Compensated Gross Tonnage (cgt), which is defined as a unit of shipyard capacity, derived from multiplying the gross tonnage by a coefficient reflecting the "standard manhour" required for production of the type of ship under consideration. These conversion coefficients give an indication of the required shipbuilding capacity - expressed in manhours - to produce one gross ton, which takes into account the complexity of the production. If more yard capacity is required to produce one gross ton, the conversion coefficient has a higher value. The conversion coefficients are determined by the working party of the OECD.

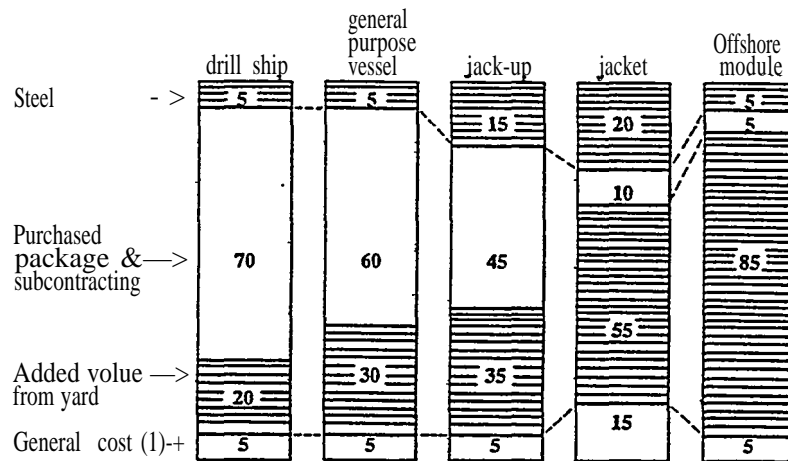
<sup>2</sup> AWES: Association of West European Shipbuilder, including the countries of the European Union (EU) as well as Finland, Sweden and Norway. The national shipbuilders organizations are represented in AWES.

continued to loose market shares.

The combination of continuing industrial growth, new market developments and the fast developing power of the Japanese industrial conglomerates initiated an industrial reorganization in the European Community. In the Netherlands mergers and take-overs led to the formation of a large industrial group in 1972, Rhine-Schelde-Verolme (RSV) owning and operating domestic and foreign shipyards and a broad scope of other industrial activities. The RSV merger took place under pressure of the Dutch government, however the expected economies of scale were, for different reasons, only partly realized. In 1983 the government refused to provide for financial help to restructure the group. Subsequently, RSV applied for suspension of payment (not to be mixed up with bankruptcy). In a very short period the group was divided into independent companies which were sold. The largest, shipbuilding facilities and ship repair facilities were stripped and closed. The newbuilding and repair capacities in the Rotterdam area alone were reduced by more than 60%.

When RSV started a total of 30,000 people were employed, of which approximately 9,000 (30%) in shipbuilding. By 1983 this was reduced to 16,000 of which 4,000 (25%) were in shipbuilding.

## THE STRUCTURE OF THE INDUSTRY



(1) Cost of financing q not included

Figure 1, Different Cost Structures of Products.

Source: Information from different Yards

The present structure of the shipbuilding industry in the Netherlands consists of small (less than 50 employees) and medium size (up to 2000 employees) shipyards and organizations. This structure includes shipyards which

cover the entire production process on one location to enterprises which combine specialized companies at different locations which jointly represent a traditional shipyard. The yards are active in varying international markets, from dredgers to naval vessels, and sometimes combine repair and newbuilding.

Some companies are grouped in a holding with other independent operating businesses, some centralized organizations, and others operate fully independent. Key functions of an organization are combined when considered useful from a business and economic point of view. The aim is to link the effects of economies of scale, and cost advantages independent of scale, originating from experience and shared operations. Some companies successfully develop new technologies which are marketed and sold to other industries.

	Nr. of Yards	Market coverage
Japan	7	92% (●).
Korea	4	90% (●).
Finland	2	80% (●).
Netherlands	15	80% (●●).

Table I Coverage of the Market.

(o) Source: K.P.M.G. Peat Marwick (1992)

(00) Source: V.N.S.I.

Note: Market coverage expressed in cgt, (compensated gross ton), or turn-over (NL).

The effect that different types of products have on the added value, and thus on the organization of a shipyard, is shown in Figure 1. The value added by a yard may vary from 20% in the case of a drill ship

85% in the case of an offshore module'. These differences have an impact on the organization of shipyards and define the structure of the industry.

Table I compares the structure of the building industry in the Netherlands with some other countries. Approximately 15 yards cover 80% of the market in volume (cgt) and 25 yards cover 80% of the market in turn-over.

More than 250 companies in the Netherlands are called "shipyards" according to the figures of the Chambers of Commerce. Approximately 100 are a member of the VNSI<sup>4</sup>, representing some 14,000 employees. The total number of employees working in the shipbuilding industry is estimated at 19,000. Many yards are active in the international market. The traditional international shipbuilding market is still covered by some 15 yards. The industry went through a difficult cult period from 1980 - 1990, but has been restructured to fit current market requirements.

The total number of shipyards in Japan is also above 200. The production structure of the Japanese shipbuilding industry is interesting in that the seven largest yards realized 36% of the Japanese production (cgt) in 1990, and nineteen middle size yards (20,000 - 100,000 dwt) realized 38%. Some eighteen smaller yards produced 9%, according to the SAJ (Shipbuilding Association of Japan). The remaining 17% was produced by other yards. In 1992 the seven major groupings, controlling some forty yards, were responsible for 92% of the Japanese orders book according to KPMG (1) (see Table I).

In South-Korea four leading yards are responsible for nearly 90% of the orderbook, the two largest yards for 70%. Although the large yards are concentrating on tankers and bulkers, diversification is growing. A strong point is the home market. During the period of 1989-1991 an average of 95% of the South-Korean Shipowners and 98% of the Japanese shipowners placed their orders with national shipyards (1). In the European Union (EU) approximately 65% of the production capacity is for EU based shipowners.

Some conclusions can be drawn from the industrial policy of the government in the Netherlands with regard to the shipbuilding during the period from 1968 till 1983.

- The attempt to develop an industrial policy for shipbuilding, with the aim to maintain

employment,~ failed.

The economy of scale was presumably lower than expected.

- Internationalization was difficult, to a lack of time. Mergers came in a very short time span (3 to 4 years). Cultural and organizational differences were underestimated. Setting new targets and realizing them, involved much more than changing management or organizational structure.
- Technology, design and engineering were not a problem. Technological changes, new production systems, and CAD-CAM applications were introduced without any problems in an early stage of development. The question 'what about the financial results' is more difficult to answer.
- Creating a large industrial group did not create a competitive advantage. Smaller size companies seemed to be more successful.

## COST AND COMPETITIVENESS

Many factors influence "competitiveness" of individual shipyards. K.P.M.G. Peat Manwick (1) defines competitiveness as 'the ability to win and execute shipbuilding orders in open competition and stay in the business'. In general terms this means that a shipyard should be able to perform its key-functions at a competitive level.

The tools available to realize the objectives of a company are, according to Andrews and Christensen (2) :

- Target-markets (defining products and product development),
- Products (to be developed or being produced),
- Research and development (product- and production development),
- Marketing,
- Sales,
- Manufacturing,
- Labor,
- Purchasing, and
- Finance and control.

The specific definitions of these operational instruments by the management depend on the nature of the business."

For each production system organization, required capital and labor, as well as the requirements for the key functions, are different. This is also relevant for the qualifications of personnel, the requirements for physical resources, methodology eg for marketing and sales and the style of management.

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<sup>4</sup> These figures are based on products delivered by Dutch yards since 1968.

<sup>4</sup>VNSI: Vereniging Nederlandse Scheepsbouw Industrie (Netherlands Association of Shipbuilder)

### Cost-driven businesses.

Managing a shipyard in a changing market, formulating strategies and developing a competitive organization require insight in the forces driving the competition, as for instance described by Porter (Porter, 1988). These forces are influenced by different factors such as culture, labor conditions, industrial infrastructure and environmental rulings. Also, national policies and the relevance given by a government to the maritime-industries to create favorable industrial conditions for the development of an attractive industrial infrastructure play a role. However, most of these factors are external to a company and this requires a sectoral approach.

Shipping and shipbuilding are continuously faced with new entrants. Low-cost shipbuilders are influencing the international competition. A well developed second hand market in shipping keeps shipowners with relatively low capital investments in competition with shipowners operating with capital intensive, high-tech vessels. The available transport capacity is close to the required peak demand for capacity. A small reduction in demand has an immediate downward effect on the freight rates.

These conditions are forcing shipyards and shipowners to a continuous search for cost reductions and make these businesses primarily cost-driven, rather than technology-driven. Considering the market conditions, the shipyard activities - from marketing, through building and construction methods, purchasing (make or buy decisions), design, the role of the supplying industry, after sales services, building technologies, quality assurance, etc. - should be reviewed and analyzed as a total system, taking cost as a leading factor.

Shipyards may assist shipowners to reduce cost eg by improving the price/performance relation of a ship by proposing a better fit in a transportation system (market 'analysis), reducing the delivery times (production) or applying intelligent financial engineering. Shortening the building period and delivery time reduce financing cost for shipowners.

A cost-effective production system, production-friendly ship design shorter lead-times and financial engineering maintain the competitive position of a shipyard

### THE SECTORAL APPROACH

The sectoral analysis compares the development of 'factor costs' within the shipbuilding industries of the main shipbuilding countries, the level of subsidies is left out of consideration. As the price of most intermediate products (such as steel) are assumed to be

determined internationally and equal to every y much attention is paid to the relative cost of labor. indicator, which reflects the competitive position, is "labor cost per unit of production in a compar currency.

Since the end of the seventies a research project was started; partly funded by the government, partly the shipbuilding industry, to establish economic parameters and indicators which would enable assessment of the competitive position of the Dutch shipbuilding industry. The indicators which have been developed are:

- World market shares (based on production compensated gross tons (cgt) by country),
- Ship production in cgt by country and type of ship, indicating the degree of specialization,
- Labor costs in the shipbuilding industry (expressed in national currency), and
- The influence of the exchange rates of national currencies expressed per US \$.

The comparison of the costs in shipbuilding over a certain period are calculated on the basis of:

- The productivity of labor, measured in compensated gross ton (cgt) per man-year,
- The direct labor cost per cgt, and
- The share of the cost of suppliers and subcontractors.

The production on the world-market.

Since the middle of the seventies the production of seagoing merchant vessels is in decline. From 1975 to 1989 the production went from 20 million cgt to 9.9 million cgt. Production increased to 11.7 million cgt in 1990 and gradually to 12.1 million cgt in 1992. The position of the Japanese yards is gradually decreasing in favour of the South-Korean yards. Together they share more than 50% of the world production. The position of Taiwan, China and Singapore during the years 1985-1992 remained stable between 2% and 2½% each. At the same time the share of AWES dropped from 40% in 1975 to 28% in 1992, in favour of the American shipbuilding industry. AWES annual production averages approximately 3 million cgt's. Until 1992 Germany is the most important shipbuilding country followed by the AWES with a market share of 25 percent. Italy and Spain also form important shipbuilding countries with average market shares of over 10 percent, (see Table I and Table III).

	1989	1992
<b>ASIA</b>	<b>57.6</b>	<b>59.5</b>
<b>CPE</b>	<b>15.2</b>	<b>7.4</b>
<b>others</b>	<b>3.0</b>	<b>3.3</b>
<b>AWES</b>	<b>24.4</b>	<b>29.8</b>
<b>(of which EU)</b>	<b>(19.8)</b>	<b>(24.8)</b>
<b>Total</b>	<b>100.0</b>	<b>100.0</b>
<b>cgt</b>	<b>(9.9)</b>	<b>(12.1)</b>

Table II. World Production in Shipbuilding  
1989/1992 Share of Production (% cgt)

Note:

Asia includes:

Japan, South-Korea, Taiwan, Singapore and China.

CPE (formal Central Planned Economies) includes

Bulgaria, Poland, Roumania, former DDR,

Soviet-Union and Yugoslavia.

Source: AWES, Lloyds, Van Holst & Koppies (4).

	1989	1992
<b>Germany (incl.DDR)</b>	31.9	25.4
<b>Spain</b>	11.5	11.4
<b>Italy</b>	9.7	10.2
<b>Denmark</b>	7.4	9.1
<b>The Netherlands</b>	6.1	11.6
	66.1	77.7
<b>Total EU</b>	80.8	84.1
<b>others AWES. Finland.</b>		
<b>Norwegian, Sweden</b>	19.2	15.9

Table III. Share of AWFS Production in  
Shipbuilding 1989/1992 (% cgt).

Source: AWES. Van Holst & Koppies (4).

#### The Netherlands compared to AWES

The Dutch production varied from 170,000 cgt's in 1988/1989 to over 400,000 cgt's in 1992. The share of the production (cgt) of the Netherlands within AWES increased from 6.1% in 1989 to 11.6% in 1990, while the order intake dropped from 6.9% to 5.1%. In the period from 1984-1988 Dutch shipbuilding production varied between 9.8% (1984) and 6.9% (1988). The average order intake was around 6%. Due to their relatively strong competitive position the shipyards in The Netherlands have been able to maintain a central position as a shipbuilding country within the AWES. In the period 1984-1992 the Netherlands had an average market share of approximately 8-9 percent in the total AWES-production.

The five countries with the largest share in AWES production in 1992 are shown in Table III. During this period the share of the EU countries in the AWES order

intake increased from 84.1% in 1989 to 88.1% in 1992.

#### The value produced per cgt

Market share and value produced are both indicators for judging the trend of the development in an industry in the market. The production values are not unambiguous. Some countries are providing the information based on total value sold, this means inclusive indirect taxes and subsidies. Other countries do not include these. The value produced is measured as the three yearly progressive averages of the values produced per cgt in US\$ (see Table IV).

	1989	1992
<b>Germany</b>	<b>1.18</b>	<b>1.03</b>
<b>Spain</b>	<b>1.38</b>	<b>0.78</b>
<b>Italy</b>	<b>0.88</b>	<b>0.82</b>
<b>Denmark</b>	<b>0.66</b>	<b>0.64</b>
<b>The Netherlands</b>	<b>2.02</b>	<b>1.80</b>
<b>AWES</b>	<b>1.21</b>	<b>1.01</b>

Table VI. Complexity of Ships Delivered (cgt/gt).

Source: AWES. Van Holst & Koppies (4).

The values show large variations from 943 (Portugal 1990) to 3910 (Spain 1990)<sup>6</sup>.

#### The export

The production for a home market is an important issue as can be seen from the Japanese and South-Korean examples. However the market for sea going merchant vessels is an international market. The percentage of export orders is an indicator for the competitive force on the world market. In general, shipyards will try to increase the share of export orders to improve chances for continuity.

The share of export orders differs much from country to country (see Table V). Italy and Denmark concentrate on the home-market, while Spain, Germany and Finland score high for export. The share of export in the Netherlands is increasing.

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The three yearly progressive average of the value per cgt is obtained by converting production values of different countries to US\$ and then calculating the quotient between the values and cgt's produced. From this quotient the average over three years is calculated

This indicator is not very reliable because of the differences in input and the impact of the differences in Cgt..

	1989	1991
Germany	not known	69.2
Spain	48.6	74.3
Italy	3.6	0.0
Denmark	12.0	0.0
The Netherlands	24.8	49.0
EL'	35.1	45.3
Finland	75.3	100.0
AWES total	43.8	50.8

Table V. Export Share of Production (% cgt).

Source: AWES, Van Holst & Koppies (4).

The complexity of the vessels.

The complexity is measured by dividing cgt's by gt's. A high ratio is an indicator for more sophisticated and special (not necessarily complex) vessels. A relation can be made to the composition of the products. For this purpose a diversification index has been used and the compilation of ships built during a certain period. The complexity of the production is shown in Table VI.

	1989	1992
Germany	1.18	1.03
Spain	1.38	0.78
Italy	0.88	0.82
Denmark	0.66	0.64
The Netherlands	2.02	1.80
AWES	1.21	1.01

Table VI. Complexity of Ships Delivered (cgt/gt).

Source: AWES, Van Holst & Koppies (4).

Diversification

The diversification used by Van Holst & Koppies (4) has been defined as:

$$DI_c = \left[ 1 - \frac{1}{2} \sum_i \left( \frac{P_{ic}}{P_{tc}} - \frac{P_{i,AWES}}{P_{t,AWES}} \right) \right] \times 100 \quad (1)$$

- $D_{ic}$  = Diversification index of country  
 $P_{ic}$  = Production of i ship type in a country  
 $P_{tc}$  = Total production in a country  
 $P_{i,AWES}$  = Total production in AWES of i ship type  
 $P_{t,AWES}$  = Total production in AWES countries.

Table VII shows the diversification index (1991) for some countries:

The figures from Table VII should be seen in relation to Table III (share in production), Table V

Germany	69.5
Spain	41.5
Italy	54.6
Denmark	34.4
The Netherlands	61.6
AWES	100.0

Table VII. Diversification Index.

Source: AWES, Van Holst & Koppies (4)

(export share in % of production) and Table VI (complexity of ships). A relatively high diversification index and complexity show an increasing or high share in production and export. A low complexity and diversification (Spain, Denmark and Italy) do not necessarily go together with high export shares. Spain seems to be an exception. Table VI and Table VU show that The Netherlands is producing relatively complex vessels, in combination with a diversified building programme.

### Portfolio Analysis

In order to judge the position of the Dutch shipbuilding industry against the different market segments of the AWES market, a portfolio-analysis is performed. To this purpose the Dutch market shares of the different types of ships in the AWES production are compared with the average yearly growth of the AWES production of the different types of ships in the period 1984-1991 (see Table VIII). The AWES market is divided in ship types showing an increasing (positive) production output and ship types showing a decreasing (negative) production output (in cgt). The Dutch market share is divided in market shares above and below 5%.

	Dutch market share < 5%	Dutch market share > 5%
growth AWES positive	crude oil tankers LPG carriers passenger ships	general cargo ships reefers fishing vessels
growth AWES negative	bulk carriers combined carriers ro-ro vessels car vessels LNG tankers, ferries	product tankers chemical tankers full container ships other non-cargo vessels

Table VII. Portfolio-Analysis of Dutch Shipbuilding period 1984-1991.

Source: AWFS, Van Holst & Koppies (4).

The AWES production of bulk carriers, combined carriers, ro-ro vessels, car carriers, LNG tankers and ferries decreased in the period 1984-1991. For these types of ships the Dutch shipyards had, however, a smaller market share. The AWES production of crude oil tankers, LNG tankers and passenger ships increased

during the considered period. Some market segments are expected to grow and can be considered as growth markets.

On the market segments of product and chemical carriers, full container ships and other non-cargo vessels, The Netherlands maintain a relatively strong position. However, the AWES production of these types of ships has shown a decline in the period 1984-1991. Should the decline in the demands for these types of ships continue in the AWES market then the concerned Dutch shipyards in these markets will be experiencing tougher competition.

Taking into account the relatively constant level of the Dutch market share in the years 1984 to 1992, it may be expected that in the segment of other non-cargo vessels, the Dutch shipbuilding industry will be able to withstand this possible stronger competition.

The analysis of ship types indicates that the major markets (domestic and international) for the shipyards in the Netherlands are general cargo vessels (21%), full container ships (20%), fishing vessels (11%), other "non cargo" vessels (30%), reefers (7%) and product/chemical carriers (8%). In these categories the Netherlands holds a relatively strong position in the AWES countries.

## THE COMPETITIVE POSITION

Labor costs are an important indication for the competitive position of a nation's shipbuilding industry. To make an international comparison, major factors that play roles are, labor cost (per manyear), the currency and exchange rates of the various countries, (expressed in US\$), and the production per manyear.

### Labor productivity

Labor productivity in shipbuilding can be estimated by dividing physical production employment into two types.

In view of the Labor productivity it is important to distinguish two types of employment. Direct employment concerns those employed directly by the shipyard concerned. Labor productivity has also to take into account the employment involved in subcontracted work because this contributes to the total production. For example, in The Netherlands a trend towards an increasing significance of subcontracting is observed in the shipbuilding industry. The increasing degree of subcontracting is indicated amongst others, by the fact that the share of the gross value added (which consists of indirect taxes, minus subsidies, labor costs and depreciations) in the production value has decreased from 33.1% in 1985 to 28.5% in 1992. Due to subcontracting a larger part of the value is added

outside the shipyard. In Japan the level of subcontracting is also substantial. To take relatively large fluctuations of production per year into account labor productivity is calculated as the average of the three-yearly progressive indicators of annual production in cgt's per manyear.

	productivity per cgt/ manager	labor cost per manyear (s)	labor cost per cgt (s)
European Community	63	97	150
The Netherlands	100	100	100
Former FRG	85	123	144
Japan	101	122	121
S-Korea, Taiwan	60	41	65
Poland	15	10	70

Table IX. Estimated indices for Competitive Factors for the Shipbuilding industry (selected countries The Netherlands 100).

Source Van Iliolst & Koppies (4)

An international comparison of the levels of labor productivity show that there is a difference between Japan and the average of the European Community with Japan far ahead (see Table IX). Within the European Community, The Netherlands shows the highest productivity, comparable with Japan, followed by Germany, Denmark and Norway. The level of productivity of countries like South-Korea and Taiwan are comparable with the average of the European Community. The level of labor productivity of Poland as an example of a country in transition, is about one fourth of EC's average.

### The labor cost per manyear

Within the European Community the former Federal Republic of Germany has the highest level of labor costs per manyear in US\$, about 20 percent above the average level in the European Community. The labor costs per manyear in the Netherlands are in a center position of the AWES countries and comparable to the average of the Community. Labor costs per manyear in US\$ in Japan is relatively similar to that of Germany. The labor costs of countries like South-Korea and Taiwan are about 50 percent of the average level of the European Community. The level of labor costs of Poland amounts approximately to one tenth of EC's average approximately.

### The exchange rate

The development of the exchange rates is important for an internationally operating Industry like the shipbuilding industry, because it determines the



prices of the products. The development of market prices is based on prices of ships delivered, consideration given to exchange rates. Reference with exchange rates are German Marks (DM), Japanese Yen and US\$. In particular, attention is given to a comparison between the West-European shipbuilding nations (AWES-countries), the principal South-East Asiatic shipbuilding countries (Japan, South-Korea and Taiwan) and Poland.

Within the EC some countries recently have come forward with a so called hard currency, especially the Netherlands and Germany. In relation to the currencies of these countries the value of the US\$ has decreased the most. A hard currency means a competitive disadvantage for the exports of the country concerned, because the prices expressed in foreign currencies increase relatively faster than might be expected on the grounds of national cost developments. Weaker currencies which, like the dollar have decreased in value in relation to the hard currency, include among others the Spanish peseta, the Portuguese escudo and the Italian lire. Outside the European Community the value of the Japanese yen also rose relatively large against the US\$. In the shipbuilding industry this can be (partly) countered by a well developed policy for a purchased package. Large parts of steel fabrications and equipment supply can be subcontracted considering changes in currency. It makes the financial engineering more complex and the yard has to obtain the knowledge of the risks which are involved. The Netherlands Export Credit Insurance covers for example only the value produced in the Netherlands which is a complicating factor for export financing.

#### The labor cost per cgt

The labor cost per cgt produced is calculated by dividing the labor cost per *many* year by the cgt per year. In order to correct for fluctuations in production and employment the calculation of the labor cost in US\$ per cgt is based on the average of three year production.

A comparison of the levels of labor cost in US dollars per cgt show strong differences. The South-East Asian countries, Japan South-Korea and Taiwan, have the lowest level of labor cost per cgt. considerably lower than those of the AWES countries. The level of labor cost per cgt in the Netherlands is the lowest within the AWES, with Denmark and Norway nearly as low. The level of labor cost in US\$ of the Polish shipbuilding industry has passed the level of South-Korea in the past few years.

A evaluation of the competitive factors is presented in Table IX for selected countries.

The am findings are reflected in the structure of Dutch shipbuilding industry as well as the market

policy and production approach of the individual shipyards. The industry is defined as a fragmented industry with many individually operating yards. Most shipyards are specialized in a limited number of ship types or a very specific market (eg fishing or dredging). Subcontracting and specialization in production are increasing as well. Many efforts are made to realize cost reduction. The following paragraph describes the effects of the factors discussed so far.

#### POTENTIAL FOR COST REDUCTION.

Porter (Porter, 1989) states that individual companies are able to create entry barriers to improve their competitive position. Examples follow.

##### Economies of scale.

The goal of economy of scale is to reduce the unit cost of a product or a part of a produce for instance by increasing the production volume. Enabling technologies are the industrialization of production process (prefabrication or panel-line fabrications), combining capacities to increase output implementation of new technologies through the reduction of overhead costs by joint purchasing. The structure of the shipbuilding industry in a country changes when individual shipyards are realizing economies of scale.

##### Vertical integration.

Advantages of vertical integration are the reductions of joint costs. The successive stages of production or distribution are combined. This also includes to the association with subcontractors and equipment suppliers. In practice it is nearly impossible for a shipyard to restrict the supplier or sub-contractor from using jointly developed know-how elsewhere. Also strategies leading to vertical integration are changing the structure of the industry.

##### Cost advantages independent of scale of a shipyard.

Some examples of cost advantages independent of shipyard size are:

- Favorable access to raw materials,
- Convenient geographical locations,
- Proprietary product technology?

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<sup>7</sup> *With regard to the proprietary technology the remark should be made that it is difficult in shipbuilding and shipping to protect product know-how by patents or proprietary agreements.*

- Learning curves, specialization.
- The development of standards, leading to cost reductions.

Benefits of specializing parts of the production system are found in decreasing cost per unit and capital cost. The classic learning curve (the result of experience through specialization), improved working methods, a refined lay-out and use of equipment, increased performances of labor, and better dimensional control with advanced measuring techniques are all requesting in declining costs per unit and improved quality (Schonberger, 1986).

### Engineering

A potential for cost-reduction is directly related to engineering activities. Some basic rules can be found in (Ehrenspiel, 1985) as follows.

- Reduce demands during the problem definition by minimizing accuracy and tolerances, and specify only conformance to standards.
- At concept stage use the smallest size and the lightest construction.
- Use simple and robust physical solutions.
- Reduce complexity. Limit as far as possible the number of parts, quantities, lengths, etc.
- Standardize as much as possible.

### Quality and Safety.

To measure quality and safety industry-wide, norms and standards are required as well as references to determine the "value of quality" in terms of money. There is no purpose in promoting quality in cost-driven industries if there is no financial reward. A well developed second hand market prohibits the introduction of quality in transportation when quality, and therefore safety, is not a concern of the shippers.

Safety is the result of commercial evaluations and in a few cases a matter of (incident driven) public concern. When norms and standards are not available, quality can only be measured by using administrative procedures or by judging the performance of the product. The role of classification societies and insurance companies is crucial when performance of ship and crew are to be measured. Complicating factors are the life time of a ship (up to thirty years or more), changing ownership during the life time of the ship, different modes of operation, and different attitudes towards maintenance.

### Lead times

Reduction in lead times are attainable through actions such as:

- Increasing the production capacity of a single yard
- Maximizing flexibility of labor between departments,
- Subcontracting production capacity with other yards,
- Sharing specialized production capacity with other companies,
- Increasing the productivity of the organization, and
- Simplifying the product.

Methods should be developed to judge advantages and constraints of a (combination of) solutions. The impact of new technologies and investments on products and productivity should be measured. Validation of new ideas should be done by administrative tools and scenario's enabling an individual shipyard to evaluate the cost performance of changes. Figure 2 illustrates that a major part of the costs are fixed during the design and engineering phase.

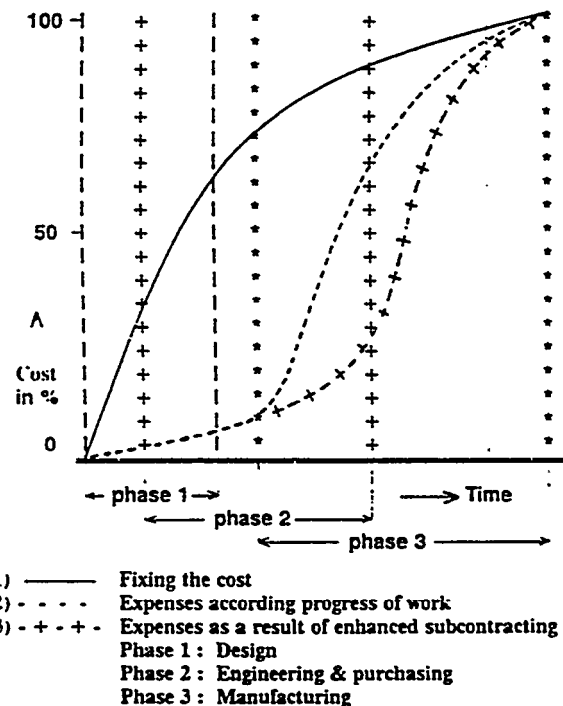


Figure 2. The Impact of Different Phases of the Production-Process on the Total Cost of a Project.

Source: Information from Different Yards

The expenses occurred during the contract period are shown in Figure 2. These expenses can be delayed by subcontracting. The effects of delaying these costs by

subcontracting are shown in curve (3) (compared to curve (2)). Subcontracting will delay payments (due on delivery) while simultaneously the total construction period can be shortened. This will decrease financing costs during construction.

The impact of the lead time on pre-financing cost is also reduced. Through subcontracting the expenditure curve is influenced. The total cycle of design - engineering - subcontracting - purchasing and fabrication has an impact on the cost of financing.

#### Standardization

Standardization is a matter which should get the highest priority. So far a multitude of standards have been developed in many countries. In many occasions these have been used to protect the national industries, by creating small differences in material specifications or dimensions, using different measuring systems, requiring approvals of specific testing facilities, etc.

Standardization on a national level has been leading to a diversification which has been creating barriers for further developments and competition, dividing an already small market into even smaller pieces. The necessity to stimulate the further development and application of International Organization for Standardization (ISO) standards is evident. ISO-TC8, the technical committee for shipbuilding of the ISO has been working on this for a long time.

Development of standards may under no circumstances hamper innovative developments such as open-top container ships. Standards should on the contrary, enable the industry to demonstrate the capability to develop cost-effective safe and environmentally friendly tools for waterborne transport. This means that the International Maritime Organization (IMO) rules and regulations can refer to ISO standards for rules and regulations. These standards have to be a concern of the shipping and shipbuilding industry in the first place. National authorities have to stimulate the industrial participation.

Structural and organizational changes affect the production process. Specialization of engineering and of parts of the production process enhances the productivity of the yards. Shipyards may combine efforts for R&D of advanced technologies (eg CAD/CAM applications) and new specialized production facilities will have to be developed.

Management, organization, administration.

An example of the administrative support for management is the control of progress. Changing the production system and shortening the lead times require close control of progress and cost.

Observations during studies carried out by the Delft University of Technology at Dutch shipyards confirm the views of Schonberger (5) that the lead time is a governing factor for costs. Progress can be measured, according to Schonberger, by controlling two conditions:

- All materials for a product going to the shop floor, and
- The finished product leaving the shop floor.

This type of control is only feasible if the lead time for (apart of) production is a few days.

Administrative and supervisory procedures can be simplified. For a shipyard this is not a realistic condition for all the production activities. A simple method to control cost and progress with longer lead times was developed in cooperation with a shipyard in the Netherlands. (8). The method is based on the material flow registered from the warehouse.

The "entry barriers" mentioned by Porter (Porter, 1980) are areas where cost reductions can be realized by an individual shipyard. Areas for further investigation to improve competitiveness of the shipyard are

- relations and communications of yard-management with labor to improve productivity, and

Means to improvement productivity	Required effort of management for change	Investment required for change	Improvement of:	
			labor productivity	production time with same productivity of labor
1. Improve organization	+++++	+	+++++	+++++
2. Automation	++++	+	++++	++
3. Mechanization	+	+++	++	++
4. Add personnel	+	++++	none	not realistic

Figure 3, Effect of "Actions for Change" on Productivity and Delivery Time.

Source: S. Hengst, R.W.F. Kortenhorst (1993)

evaluation of the structure of the industry ie the relationship between shipyards and suppliers or subcontractors.

*Some* views in the Netherlands are represented in Figure 3 where the means to improve productivity are set against the required effort of the management the financial means, the impact on labor productivity, and lead-time. (Hengst, 1993).

"Improve the organization" is the message, assuming that the production technology for pre-fab, and design and engineering is well developed.

Improving the organization is demanding a larger effort from management than automation, mechanization, or extra personnel. Labor productivity will increase, leading to reductions in production time. As long as the investment for the change is low, the effect on the overall cost is evident. The effects on cost of automation and mechanization are claimed to be less.

The structure of the industry and increased subcontracting.

possible with a standardized modular approach - is demonstrated by the vertical arrows. The logistic support is generated from the desing/engineering stage by assuring that materials are combined with the necessary information for unobstructed assembly.

Design and engineering are primarily controlled by the availability of (external) information. The lead times of pre-fabrication are governed by the capacities of production facilities while the lead times of the pre-outfit depend on delivery times of the long lead equipment- The production systems in shipyards consist of different types of production processes eg process production (materials handling and pre-fab), series production (panel-line and some parts of pre-assembly) and unique product production (assembly). Suppliers can specialize in any of these production technologies.

Specialization in pre-fabrication is possible if the preparatory activities of engineering meet the required production schedules. This includes ordering of steel, the preparation of the numerically controlled pre-fabrication of plates and profiles, and the timely and

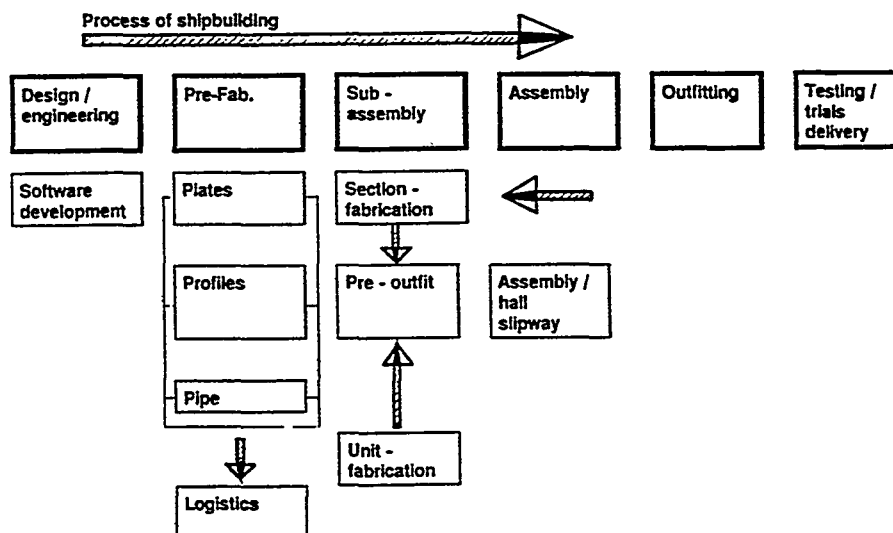


Figure 4, Selection of (building) Policy.

Source: S. Hengst, R.W.F. Kortenhorst (1993)

Reference is made to the production phases shown in Figure 4. The arrow on the top indicates the sequence of the phases of a typical production process in shipbuilding. The second from top arrow indicates the trend that the outfitting is gradually moving to the assembly and pre-outfitting stages. When the final outfitting disappears, the process, and thus the delivery period, is shortened by one phase.

The role of pre-outfitting - a combination of section fabrication and unit fabrication, as much as

precise grouping of all materials required for sub-assembly.

The type of assembly changes the requirements for engineering and work preparation compared to the traditional shipyard. Engineering and the preparation of the work may be subcontracted to suppliers of modules or completely pre-outfitted sections.

Strategic selection of production activities.

The selection of production activities for a shipyard - ie a "make or buy" decision - should be based simultaneously on analysing cost, lead time and quality. A shipyard has to decide which parts of the production are to be considered as core activities of production, essential for the continuity of the company. The preparation of such decisions requires tools for the management to be able to evaluate and compare different options and develop solid financial and economical policies. The conditions will vary for each individual shipyard and the product selection made by the yard. In other words a niche-market approach and specialization require a careful review of the production system. Building dredgers is not the same as building chemical carriers.

### CHANGES IN SHIPYARD ORGANIZATION

Traditional shipyards were based on *vertical integration with the* fabrication of as much equipment as possible, such as changes, turbines and main-engines, as well as facilities for all aspects of production including foundries, machine-shops, pipe-shops and carpenter work. It included nearly every type of work required to build a ship and "added value" to shipyard production. The total production process was fully controlled at a yard. Delivery times were controlled by spreading and levelling capacity of the yard, or by subcontracting.

Spreading the shipyard capacities to subcontractors and suppliers may be called "*horizontal diversification*". Horizontal diversification of the production process (through subcontracting) puts constraints on the effectiveness of the production process of a shipyard. The effectiveness of an organization will depend on the size of the operation.

For smaller size yards problems may occur, because the balancing of the capacities of departments to obtain the shortest possible lead times becomes more difficult. Efficient use of the production facilities of a department, eg by increasing the production volume to the maximum capacity, may not be possible. The opportunity to obtain reductions in cost per unit remains unused in situations where capacities cannot be balanced. Particularly in case of batch- or process-type production systems, cost reductions can not be realized when the production capacity of a unit cannot be fully employed, such as when limited to the demand of one shipyard. The total production system does not usually allow for levelling the production capacities of single departments. Moreover, the degree of utilization of equipment and machinery will vary as a consequence of different types and sizes of ships which are under

construction. The production system under these conditions is faced with additional rests which have to be accepted.

Changes in The Netherlands.

Specialization of subcontractors and suppliers initiates changes in the shipbuilding industry and makes it possible to buy an increasing amount of equipment and services from suppliers. The cost structure shown in Table X illustrates the importance and the effects of the changes in the industrial structure as shown in Figure 5.

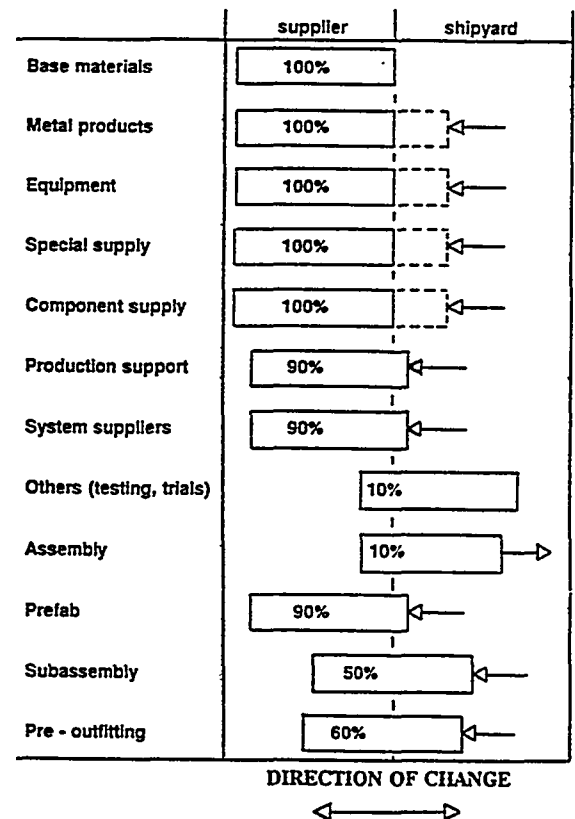


Figure 5, Changing Structure of the Industry (illustrative only)  
% of work moving to suppliers

Source: Information from Different Yards

These changes in the structure of the industry are the result of the need to improve the competitive position, and coincides with the strategic development towards diversified niche-oriented shipyards. This is confirmed by the findings of Van Hoist & Koppies.

A process of *horizontal diversification* combined with specialization means increasing Subcontracting without, affecting the market-position of shipyards. "Make or buy" decisions are becoming a relevant topic

• **Materials** (increasing)

- base materials	7%
- metal products	6%
- equipment	24%
- special supply	3%
- system suppliers	15%
- component suppliers	3%
- others	2%

• <b>LABOR</b> (decreasing)	60%
• <b>CAPITAL CHARGES, SERVICES</b> (increasing)	30%
<b>TOTAL</b>	100%

Table X. Cost Structure General Cargo Vessel

Source: Information from Different Yards

for a shipyard to reduce cost. The result is a different industrial infrastructure. The effects are to be found in purchasing<sup>8</sup>.

introduced and yards specialize in specific markets and types of ships. In The Netherlands this has been leading to an improved competitive position in the AWES confirmed by a gradually increasing market share.

Two types of specialization (which have apparently no relation) can be noticed.

- The specialization of the shipyards. The advantages of the niche-market approach of Dutch yards has been successful so far.
- The specialization of the subcontractors and suppliers as a result of the enhanced subcontracting of the yards.

Shipyard specialization is combined with increasing complexity and diversity of products. At the same time the productivity of shipyards is increasing. Both in Japan and in the Netherlands this is combined with an increasing amount of subcontracted work. Apart from productivity improvements resulting from modularization and pre-outfitting, the productivity is apparently improved by specialization of the subcontractors and suppliers. Not only are total engine room or pump room installations subcontracted to specialized subcontractors, but also pre-fabrication, pre-

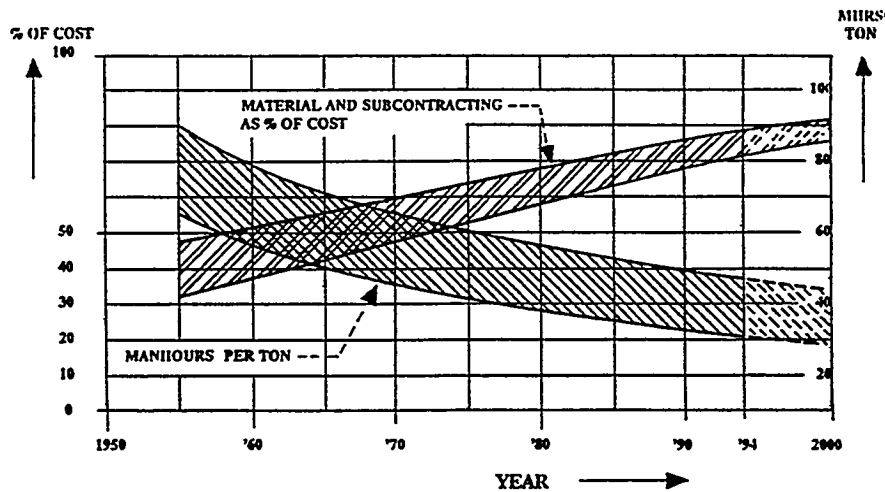


Figure 6, Development of Added Value Compared to Material + Subcontracting

Source Information from Different Yards

Shipyards should concentrate on core production activities. Production is no longer just a matter of combining available manpower and physical capacities, or trying to build any type of ship. Market analysis is

<sup>8</sup> The aim of some (eg Japanese) yards is to reduce the added value of the yard 30- 35% of the total cost of the ship to 10- 15% in the coming years.

assemblies, panel-line productions, stem and bow sections, double bottom and shells, etc.

To explore where further progress can be achieved, the effects of improving the quality in the upstream stages of the production process (engineering, purchasing, material handling prefabrication) will have to be included in the evaluation and weighed against the impact on the production stages down-stream the process, eg the assembly.

Other savings may be found in sharing investments in eg the up-streams activities between different shipyards. In the northern part of The Netherlands some eight yards combined investments in engineering (CAD-CAM), soft-ware development, pre-fabrication etc. The required capital demand up-stream, as sophisticated computer applications costly up-front research and software, are limited with combined purchase and shared operation between shipyards and subcontractor. The competitive advantages of such an operation are proved in international competition.

The advantages of horizontal diversification are spreading of capacity to subcontractors, resulting in an increased flexibility of a yard, maintaining the capability to realize short lead times in combination with cost-reductions. Individual yard capacity is then no longer a decisive factor for lead time or capacity.

The effects of these developments in The Netherlands are shown in Figure 6. The percentage of material and subcontracting, as a percentage of the total cost, has been gradually increasing during the last 45 years. At the same time the manhours per ton constructed steel have gradually fallen.

The trend is confirmed by the findings by Van Hoist & Koppies, indicating that shipyard productivity (based on a three yearly progressive average) increased from 42 cgt per manyear in 1985 to 81 in 1991, showing a yearly growth of 11.5%. For comparison, the figures for Japan are 69 and 82, South Korea 23 and 35.

The threads of horizontal diversification.

The attitude, bargaining power and the strengths and weaknesses of the suppliers to the shipbuilding industry are becoming more important. The shipbuilding industry is often not a first priority customer for suppliers because the market volume is limited compared to the total sales volume of the supplier. A relationship between equipment suppliers and shipowners (eg paint navigation equipment or propulsion systems), weakens the position of shipyards. Yards may then re-investigate vertical (backward) integration. On the other hand, the cost of a product from suppliers sometimes represents only a small part of the total cost of a ship, and the penalty for failure or late delivery of equipment (or ship) may be high in relation to the cost of vendor supplied items. A reliable supplier is then of the essence.

Another question is how far the process of *horizontal diversification can be used* without weakening the position of a shipyard. A problem may be the niche market selection. A shipyard may try to cover as much of any market as physical capacity will allow. On the other hand, the advantages of niche markets are evident as shown before, and this may

oblige a yard to maintain manufacturing functions which are indispensable for product development.

A shipyard might be caught in a strategic "trap":

- maintaining a capacity for a specialized share of the market, running the risk of "idle periods" or
- serving larger parts of the market with the same capacity acting as a jobber at "cut throat prices".

**Horizontal diversification** of the industry means enhanced subcontracting and has the advantage of

- spreading the capacities,
- increasing the flexibility of the individual yards, and
- maintaining the capacity of the industry.

In order to be able to take a strategic "make or buy decision" a yard has to decide which parts of the enterprise are to be considered as *main functions*, *indispensable* (conditional) *functions* and non-essential *supporting functions* for the continuity of the company. The preparation of such decisions may be supported by an analysis of different scenarios comparing different options and developing financially and economically justified policies.

The building of a steel hull, which represents approximately 75% of the added value from a shipyard to the cost of a ship for the merchant marine, is also no longer one of the core manufacturing activities of the shipbuilding industry. Production concentrates on final assembly, and final assembly is becoming one of the major shipbuilding activities. Sub-assembly and pre-outfitting are more frequently subcontracted to specialists<sup>9</sup>.

The main reason for these changes are initiated by the need to remain as a seller on the buyers side. The added value of the shipyard is no longer the decisive factor. Financial aspects such as currency, quality, service and standardization of the suppliers are becoming essential factors.

## EXPECTED MARKET DEVELOPMENTS

The expectations are that transatlantic and intercontinental shipping will show increasing sizes of container vessels, and other cargo vessels able to carry.

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*' An illustration is the view that the building and construction of a steel hull is typical for a shipyard. Some shipyards in the Netherlands prove that this is no longer the case (Damen Shipyards and Central Industry Group). The shipbuilding industry is getting more and more concentrated on the final assembly of the ship, with testing, trials and delivery on one side and marketing, design & engineering on the other side.*

cargo in bulk a similar development as has been seen by tankers and bulk carriers. Containerization is expected to increase and may get the characteristics of bulk transport. According to the studies carried out by the Port of Rotterdam, container traffic will grow by more than 300% in the coming 15-20 years. The cargo will be more and more "condensed" and "concentrated" in volume and size. The increasing ship sizes for intercontinental transport will lead to the "hub and spoke principle with mainports. On-shore long-distance trucking continues to increase, but expectations are that the relative growth of railways and watertransport (coastal and inland) will be bigger.

Some effects are shown in figures 7, 8 and 9. Figure 7 illustrates the case of two mainports in Europe, one in the North-West region and one in the Mediterranean region.

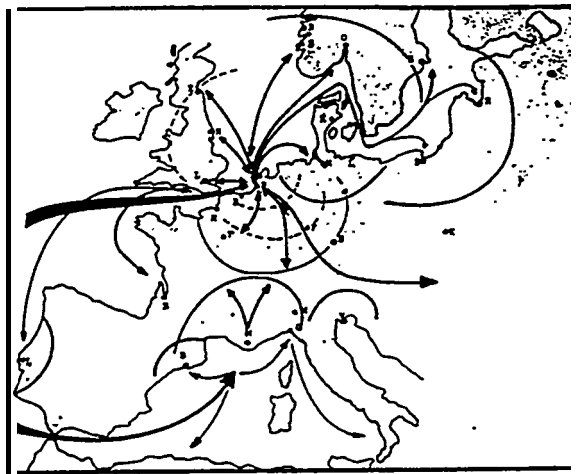


Figure 7, The Changing Market (1)  
(Hub and Spokes).

The hinterland is served from a mainport by sea-to-sea, sea-to-inland waterway, sea-to-train and sea-to-truck transfers. The different modes of transportation (the modal split) will cover specific markets, related to the types of cargo. Feeders may cover distances of 1000 - 1400 Km (600 - 850 mi) in two days. Trains may cover 2000 kilometer (1240 mi) in less than a day.

Figure 8 illustrates the coverage of different parts in the European Union (EU) for a one day trucking distance from different ports and shows that the hinterland cannot be served by a one day trucking system.

Figure 9 illustrates the enhanced coverage by the railway and inland waterway system, covered from the port of Rotterdam in combination with a one day trucking distance. Coastal and inland waterway shipping are expected to develop gradually into point-to-point services over the long distances (>250-350 km, >150-200 mi). This will lead to more transportation

by ro-ro, container and dedicated cargo ships.



Figure 8, The Changing Market (2)  
(One Day Trucking).

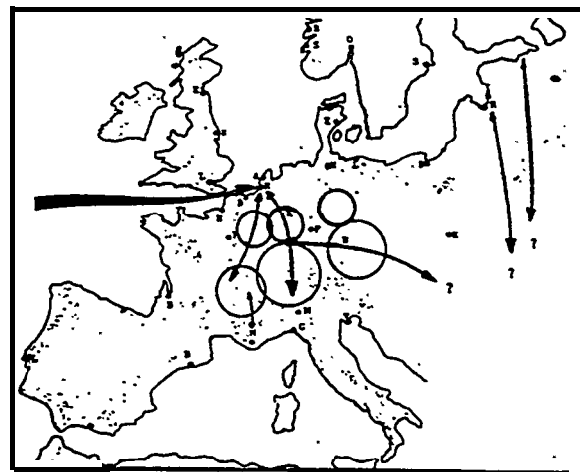


Figure 9, The Changing Market (3)  
(Effect Inland Waterway Transportation).

For shipbuilding, it is expected that the competitive position of The Netherlands can be maintained. This, amongst others, is explained by:

- A modest growth of the labor cost during the second half of the eighties compared to other AWES countries,
- The level of production per manyear,
- The relative low level of labor cost per cgt,
- A well defined niche-market approach and
- A cost-effective application of advanced production technologies.

Competition from shipbuilding countries in Central and Eastern Europe is expected to increase.



Although a modest growth in labor cost in The Netherlands is foreseen, the international competitive position of the Dutch shipbuilding industry is expected to be hindered by an increasing value of the guilder.

The expectation is also that shipyard added value will further decrease and subcontracting and supplier content of the price will increase. Flexibility and quality of labor will have to increase further.

Purchasing will become more and more an international matter, taking advantage of changes in exchange rates and international (ISO) standards.

Shipyards capable to meet the international competition

- Are able to operate on an international level,
- Take advantage of production facilities and suppliers using cheap labor, anywhere in the world,
- Trace international means for financial engineering
- Utilize to a maximum extent the advantages offered by changes in exchange rates,
- Develop innovative cost-effective and market-oriented designs and
- Use standards which will allow for cost-effective world wide purchasing.

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# Experiences of Introducing ISO 9000 and Total Quality Management in U.K. Shipbuilding and Ship Repairing

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## ABSTRACT

This paper is based on the authors' experiences of the development and implementation of ISO 9000 Quality Management Systems (QMS) and Total Quality Management (TQM) programs in UK shipbuilding, as Quality Manager of a large UK shipyard and an independent consultant respectively.

Implementing ISO 9000 will have the greatest beneficial impact on a company's operations if, at the outset, it is clearly established as the first step towards changing the culture of the company to one of 'continuous improvement.' This must be part of the overall process of getting the business processes of the company under control as a prelude to improving their efficiency and then effectiveness.

The reality of implementing both ISO 9000 and TQM, including conversion from AQAP-1 to BS 5750, are illustrated. The place of TQM in the context of transformational change programs will be highlighted. The factors that influence the success of an effective change management program are described.

## NOMENCLATURE

### ISO 9000

The International Organisation for Standardization's standard for quality management systems. In the United Kingdom the British Standards Institution also designate this as BS 5750; these designations are used interchangeably. An accreditation certificate is marked with both identifications as well as the European standard EN 29000.

### AQAP 1

Allied Quality Assurance Publication 1; until recently this was the standard applied to suppliers by the United Kingdom's Ministry of Defence.

### TQM

Total Quality Management.

### MRP II

Manufacturing Resource Management technique.

## INTRODUCTION

Merchant shipbuilding and boatbuilding companies in Europe and North America have faced a sustained period of turbulent change in their markets for over 30 years. Now the builders of naval vessels, especially in the United States of America, have entered a period of similar severe change in a shorter period. If an investment in assembly facilities, manufacturing hardware or design software alone were sufficient to ensure competitiveness and success, many European shipbuilding companies would have easily avoided liquidation.

Merchant shipbuilding can be characterized as a medium-level technology industry that is manpower-intensive. The primary task for a shipyard to exploit this market successfully is that the shipbuilder matches the customer-facing elements of the process (i.e. meeting or exceeding the owner's expectations for product design and finance) whilst mobilizing and managing the internal resources required to deliver the product on time and at a cost that also satisfies the company's shareholders. The stability of the international shipbuilding market is a fragile one given the clear intention of the Far East yards to retain dominance of the market and the recent emergence of the East European and Commonwealth of Independent States shipyards as suppliers of additional low cost capacity into the supply side of the market.

This paper addresses the opportunities for beginning the process of effectively mobilizing and managing a company's resources. Experience from a variety of shipbuilding, and other, organizations indicates that a coherent and effective response to this degree of change is possible if the tools of Quality Assurance and Total Quality Management are employed within the context of a holistic approach to transformational change. Experiences in three organizations (both successful and less successful) that have contributed to the development of these views are summarized. Finally views are offered on how to manage a change program that will enable the organization to accept the degree of transformation that is required to succeed in the future.

The authors hope that this paper will also act as a stimulus to the shipbuilders of the United States to make the changes now that are needed before the

business environment becomes too hostile to make an effective response.

## CASE STUDIES

### Experience 1: Devonport Management Limited.

This organization had along and proud history of over 300 years of operation as a principal center for the repair and maintenance of Royal Navy vessels of all types, including nuclear submarines. It had naturally expanded greatly during the Second World War, and even in 1987 had a workforce of around 12,000 together with comprehensive facilities for practically every type of manufacturing and assembly process. It occupied one of the largest industrial sites in Europe.

The disturbance of major change first arose when the government of the day chose to divest itself of the responsibility for day-m-day management of the yard (and one other similar establishment). Private sector companies were invited to bid for management contracts; this brought an element of competition into the refit business that had previously been absent, with the attraction for the government of greater value for money. Within a short period of the award of the management contract AQAP1 accreditation was withdrawn by the Ministry of Defence.

The Deputy Managing Director was tasked with regaining the AQAP1 accreditation and he took this as a major opportunity to set the whole organization on the path towards a continuous improvement culture. A team of consultants from United Research (now Gemini Consulting) were engaged by the yard to assist in the management of the program.

When the AQAP campaign started there were eighteen weeks to prepare the yard for the assessment. In itself this represented a major exercise and the first task was to form a cross-functional task force, the AQAP team. There were eight main elements to the program:

- Scoping the task (Gap and Risk analysis),
- corporate procedure drafting,
- Engineering procedure preparation,
- Training and implementation,
- Internal housekeeping,
- Self review,
- Formal assessment by the Directorate General of Defence Quality Assurance, and
- Ongoing Quality Improvement Program.

Gap and Risk analysis This was a comparison of the existing procedures against the AQAP standard with the aim of identifying where no procedure existed (a Gap) or the procedure was inadequately written or implemented (a Risk). The results were presented and

reviewed with management and used as the basis for planning the remainder of the campaign.

Corporate Procedures Drafting these was the next step. In the past procedures had tended to be wordy documents, discouraging understanding and compliance. The new procedures were specified to be easily understood and readily usable by the first line supervisor, and capable of being audited. Flowcharts were used wherever possible and designed to fit pockets of overalls. The procedures were arranged so that managers were issued simply the procedures relevant to that department and provided with a software-based index that permitted easy updating of all revisions and rapid reference to generic subjects such as contracts or shop production control.

Engineering Procedures The third step was preparing technical process specifications. These defined key production processes such as welding and painting. The aim was to synthesize customer requirements and internal best practice in an easily understood and unambiguous form. A special sub-group of the AQAP team was setup to accelerate this process and by the time of the assessment, some 120 key processes were defined and implemented.

Training and Implementation The new procedures were cascaded through the organization, with managers taking full accountability for implementation in their departments. This required initial overview training by the AQAP team and then the training of trainers who introduced staff to the detailed content of the procedures. Compliance with the procedures had to be assured. Management ownership and commitment was demonstrated by requiring them to conduct compliance checks in other areas.

Internal Housekeeping In addition a major initiative was launched to improve standards of housekeeping and material care entitled 'Operation Safeguard.' This was taken to heart by staff throughout the yard and resulted in the removal of large quantities of scrap and general rubbish. It had an immediate and visible impact on awareness of quality standards and the benefits of compliance.

Ongoing Quality Improvement Plan The quality improvement plan was instituted in advance of the assessment as a means of capturing and planning for the elimination of non-compliances. This was specifically developed to pre-empt any tendency to 'revert to normal' afterwards. It was also used as the basis for developing a program change that has seen the introduction of statistical process control and the redesign and simplification of business processes.

A key element throughout the campaign was the integration of a communications plan, both to the staff inside the yard and to the yard's customers, into the program. This comprised a publication ('Quality Matters') to all staff and regular briefings to managers.

After successful achievement of the AQAP accreditation the lessons were drawn out. Apart from

the specific lessons concerned with the form and content of the procedures, the greatest lessons were those around the process used to achieve the success. Having established and communicated a picture of the work to be done, the team was able to generate a sense of urgency, involvement and personal responsibility among staff in a way that created understanding of what process improvement means in practice.

## Experience 2: Swan Hunter Shipbuilders Limited

Swan Hunter Shipbuilders Limited returned to the private sector in January 1986 after eight years as a member of the nationalized British Shipbuilders corporation, by means of a management buy-out. The labor force was around 3,600 staff and the facilities were capable of constructing a wide range of surface vessels up to tankers, aircraft carriers and large auxiliary vessels. The yard had established a reputation for providing high quality products to its principal customer, the Royal Navy. Even so, after privatization it was appreciated that major changes had to be introduced if the yard was to be competitive.

The story of this yard from privatization to its present position (at the time of writing in receivership) provides a number of lessons, both positive and negative, on the process of integrating Total Quality Management into a program of major change.

The first major initiative after privatization to address the question of improving performance was a series of 'Vision and Image' workshops. These were attended by managers of all levels who spent two days examining the company's strengths and weaknesses. They proceeded to define their vision of what they would-like to see the company become. The results of the workshops were collated and re-presented to the managers so that a common vision emerged. This had the added benefit of showing clearly to the people involved that they now had a direct say in the future of the company and that their views would be taken into account. This was in stark contrast to the previous culture in which managers were excluded from significant communication and policy-setting processes. An outcome of these workshops was the implementation of a Management Development Program for all levels of management, including first line supervision and the Board of Directors. A range of training programs was sponsored from supervisory qualifications to an MBA degree. Over a four year period some 400 people participated in this program. 'Learning contracts' were established between the company and individuals whereby private study was matched by study the during the working day.

Another outcome of this approach was the natural evolution of a body of staff who communicated across departmental barriers in ways previously

unimagined, and who could express views and concerns in a common language with each other.

An important ingredient in the development of the company through this period was the understanding that 'what was said was what was meant.' This assisted in the introduction of a range of agreements with employed representatives including

- Rationalized pay structures with single table bargaining for all groups of employees;
- Common dining facilities for all;
- Common coveralls with regular laundering and exchanges;
- Improved safety and weatherproof clothing for all;
- A common team briefing process for regular communications to all employees within a set time; core briefs were supplemented by local information,
- Offices redesigned and upgraded, and
- All alcoholic drinks removed from the premises.

In late 1988, an initiative called 'Enterprise 90' was set up to ensure the submission of a successful bid for a batch of Type 23 frigates in 1990. Groups made up of company directors and senior managers recommended that the company should adopt a Total Quality culture. The process was led from the top. The group's interpretation of Total Quality Management was set out as six 'bullets':

- Everyone involved;
- Systems, procedures and everything you do;
- Elimination of waste;
- Continuous improvement;
- Customers come first; and
- cost of quality.

A Total Quality Board was constituted from all the yard's Main Board directors and was advised by general managers from the quality assurance, human resources and training functions. Reporting to the Total Quality Board, a Total Quality Steering Group was established from general managers in a number of different departments. These two groups began to define the methods to be used to implement TQM. The TQM message was passed to the rest of the company by means of a briefing cascade. A consultant was employed to assist in the process.

A multiplicity of different approaches was adopted for improving 'customer-supplier' relationships. The Steering Group's recommendation was for each department to identify its two most significant customers and suppliers and to establish a 'Service Level Agreement' with them. It had been intended that these agreements should form internal contracts that would be regularly monitored to improve service delivery. However the form and content of the

agreements varied widely, which led to criticism of the whole TQM process.

At this time the company's Quality Assurance systems failed an assessment by the Ministry of Defence against the AQAP 1 standard. This was the first time that *this* had occurred in Swan Hunter's history and was a major shock given the company's pride in the quality of its product. The company's decision was to be completely redesign the quality management system as a step in the TQM process. However this rationale was not communicated to the workforce and resulted in further loss of credibility for the TQM process. The task of rewriting procedures and work instructions was given to the departments, within the framework of a Company Quality Manual. This latter document took longer to produce than anticipated by which time some departments had already begun to write their own procedures independently.

The AQAP 1 re-assessment six months later was successful. Later the company changed the basis of assessment of its QMS from AQAP 1 to ISO 9000 in line with Ministry of Defence policy. The conversion process was much smoother than could have been anticipated because a comprehensive briefing and training program was put in place. Among the changes introduced at that time was self-verification by the operators leading to reduced inspection.

The widespread dissatisfaction expressed with the process of implementation of TQM during the AQAP 1 re-assessment led the Board and Steering Group to relaunch the TQM initiative. Performance improvement targets were set out and some thirty six 'facilitators' were nominated from each department. These met at regular and frequent intervals to discuss progress. The whole program was given a boost when the 'Enterprise 90' initiative bore fruit and the company won the bid for three Type 23 frigates. The need for success in improving performance was emphasized by the requirement that the third vessel had to be produced with 25% fewer manhours than the first. Furthermore, having already built one of these ships the normal 'learning curve' savings were not available.

The facilitators had a key role in the relaunch of the TQM program which included qualitative targets such as:

- Increased visibility for the program,
- Increased participation and commitment from individuals,
- Integration of TQM into normal working practices, and
- Improved team working.

Facilitators, the TQ Board and TQ Steering Group met at bi-monthly intervals in workshop sessions to exchange experience and develop solutions to identified problems. The facilitators then took projects away from these sessions to implement in their

own areas. The facilitators also had the role of acting as the 'thought-leaders' in their own departments for the tools and techniques to be adopted, and the measurements to be put in place.

Measurement was a topic that perhaps had the most potential for improvement in the way it was addressed. Although included as one of the original six 'bullets,' identifying the cost of quality was not properly followed through. The consequences of this were that a prime source of data was missed for identifying and prioritizing areas of opportunity for improvement. Again the quality of measures put in place varied from department to department. It was noticeable that where measurement was most specific, the identification of improvement was also greatest.

The TQM program was halted in its tracks in mid-1993 as the result of the company's failure to win a contract to build an order from the Ministry of Defence for a helicopter carrier and the immediate placing of the company into receivership. At the time of writing one Type 23 frigate remains to be delivered and negotiations are continuing with a potential purchaser of the yard.

The lessons to be learned from this experience can be summarized under the headings of 'Successes' and 'Lost Opportunities.'

#### Successes

- Widespread communication of the TQM concepts and progress was achieved using the 6 'bullets', team briefings, display boards and specific communication papers.
- There was involvement of all levels of the company.
- Tangible improvement in some areas of the company's operations was made.
- Quality was integrated into company operations, not treated as a 'bolt-on goodie.'
- The training associated with implementation of quality management systems also provided a foundation for the TQM program.
- Improved teamworking and breaking down of 'functional silos' was achieved.
- Departmental facilitators acted as champions of the process.
- The Management Development Program emphasised the commitment of the company to its investment in people as a reality.

#### Lost Opportunities

- The implementation process could have been coordinated from the outset to demonstrate a 'right first time' approach from the leadership of the program.
- A comprehensive and quantitative approach to measurement of baselines and improvement in performance would have provided a sharper focus for the program overall and emphasized the

business need for the program. (This will be referred to again later in the paper).

- It could have been possible to provide training in the tools and techniques of quality and performance measurement more widely to those who required it.
- The implementation process would probably have proceeded more smoothly if pilot schemes had been used to demonstrate the effectiveness of the process improvements before introducing them across the whole organization.

### Experience 3: Marine Projects (Plymouth) Ltd.

Marine Projects is one of the UK's leading builders of luxury powerboats and sailing yachts. Typically powerboats in this market segment are priced in the range from \$150,000 to \$1 million per boat depending on size and fit out. The product range is based on a number of standard glass reinforced plastic (GRP) hulls that are updated with increasing frequency and the internal fit can be heavily customized. From its foundation in the early 1970's to the late 1980's the company experienced continuous sales growth to around \$75 million per year at the peak. The economic recession finally caught up with the company's customers and forced the labor force to be cut for the first time from around 1200 to some 550 employees, and to retrench from four factory sites to three.

The seventy and speed with which this reversal in fortunes occurred exposed some weaknesses that had been hidden, but dormant, during the years of expansion. These included:

- A lack of formal control over both the administrative and production processes, stemming from the industry's almost 'cottage industry' origins;
- Poor management information systems, and
- Reliance on individual incentive schemes to achieve output volumes.

The informality of the company's systems and procedures was identified as a weakness and the company set about obtaining accreditation to ISO 9002 (or BS 5750 Part 2). The responsibility for producing procedure documentation was left largely to the Quality Manager by departmental managers who were heavily engaged in day to day management of the business. There was little buy-in to, or support for, the new procedures, and a predictable outcome was that the first assessment was unsuccessful.

The appointment of a new Production Director was taken as the opportunity to introduce a radical program of change to the organization, under the slogan of 'Getting Our Act Together.' A Steering Group was

established that became known as the Blueprint Group composed of the senior managers in the organisation, some of whom had been recently recruited from outside the industry specifically to add greater breadth of experience to the management team.

The Blueprint Group established a number of initiatives to raise the performance and profitability of the company. These included:

- Introducing a MRP II planning and control system
- Manufacturing and assembly process improvements, and
- Obtaining accreditation to BS 5750 Part 2.

In the midst of this the marketplace intervened and required that a substantial set of product upgrades be introduced in order to offset the actions of the competition. This stretched the resources of an already lean management team to the limit, but not beyond.

The introduction of quality management systems was primarily undertaken to establish the control over business processes that had been lacking previously and to provide a firm foundation for the other improvement initiatives. One of the authors was invited to assist with this initiative. The role taken by the consultant was defined in terms of providing assistance and experience of managing this type of program; responsibility for the success or failure of the procedures was to remain clearly with managers at all levels.

A BS 5750 Steering Group was established from the senior managers and the Quality Manager. The role of this group was to confirm the overall plan and the timetable and to resolve any issues that could not be decided by any individual manager. The target for submitting to the assessment was only five months.

The initial task was to undertake a Gap and Risk analysis. The result suggested that a substantial amount of procedure rewriting would be required. Drafting of procedures and Work Instructions was carried out by groups of supervisors and operatives on the grounds that they were both the ones with greatest knowledge of the processes and also the ones required to operate to them. Training in the tools and techniques required was provided to these groups on an 'as required' basis.

A program of awareness training for all employees was established. This was followed by each manager taking responsibility for training the staff in the redrafted procedures. A program of compliance checks was put in place where managers and supervisors visited each others' areas and carried out a check to establish if specified procedures were being complied with. Not surprisingly, housekeeping figured heavily in these checks.

After successfully gaining the accreditation at the second attempt, the Production Director requested further assistance to establish performance measures, and the

management processes to review them, throughout the production areas as a structured mechanism for driving performance improvement.

## MANAGING TRANSFORMATIONAL CHANGE

### The Change Process

In this section the role of Quality Management Systems and Total Quality Management is placed into the context of what is required to transform an organisation from mediocre to outstanding performance.

An important first step towards this understanding can be summarized by a statement of the cruelly obvious:

**'CHANGE REQUIRES THAT INDIVIDUALS AND ORGANIZATIONS THINK ACT AND PERFORM DIFFERENTLY**

This begs the question of how the changes can be introduced and made to 'stic'; there countless cases of improvement programs that have generated activity for a while but then faded into oblivion when the next fad or crisis reaches the top of the pile.

One useful model of the change process is that originated by Kurt Lewin some 40 years ago and developed by Edgar Schein (1961,1969). This proposes a three stage process of:

### CHANGE

### REFREEZE

Thus change starts with something that prepares the organization or individual for change. In the case of industrial companies recently the most significant unfreezing agent has been the loss of markets. During this 'unfrozen' state considerable change can be accommodated until the time arrives when the desired new behaviours are embedded and a new period of stability can be accepted. In the light of the continued turbulence of the world's markets and the need to establish learning organizations the term 'refreeze' might be usefully redefined to indicate a state which is relatively easily brought back to the 'Change' state.

Change can range in extent along a spectrum from 'Incremental-Continuous' to 'Major-Discontinuous'. In the context of United States shipbuilders' desire to re-enter the world's merchant shipbuilding market, the need is to achieve change that is 'transformational' in nature. Common to these types of programs are one or more overarching objectives that represent 'stretch' targets, such as:

- 30% increase in productivity in outfitting,
- 25% reduction in cost on the next ship, and/or
- 20% reduction in quality failures in 6 months.

### Structuring a change program

Structuring a real transformation program requires that strategic issues are tackled in parallel with the more tangible operational ones (see Figure 1).

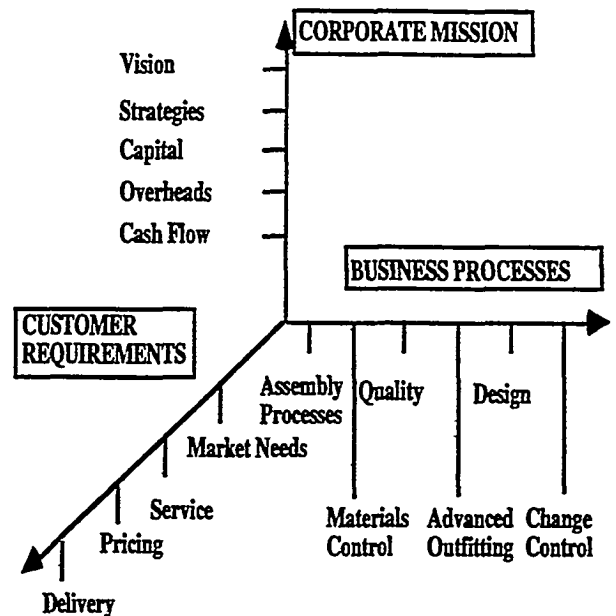


Figure 1 Multiple Dimensions of change

It is vital that there is a clear understanding of:

- What must be delivered,
- The current position,
- What must be changed and why, and
- The level of effort required.

If a transformational change program is to achieve its intended result it must also tackle simultaneously the three elements of organizational behaviour:

- Technical,
- Political and
- Cultural.

For the theoretical foundation of these concepts see Kanter, 1984, a practical application in General Electric is well described in Tichy & Sherman, 1993. There must be a clear focus and concentration on those areas of the business that will yield the greatest benefit. This is an argument for a Pareto-type assessment of the

initiatives that analysis will suggest are needed. It is in this context that measuring performance and driving performance improvement through a cyclical process of 'Plan-Do-Review' becomes a significant part of many successful programs particularly in manufacturing organizations where effectiveness of supervision is crucial for the efficiency of the operation. Shipbuilding clearly falls into this category of organization.

Inevitably this means that top-level management commitment is a critical factor for success; managers at all levels must 'walk the talk' since any lack of commitment will be spotted immediately by subordinates.

A typical change program will be phased in a way that reflects Lewin's change model (see Figure 2).

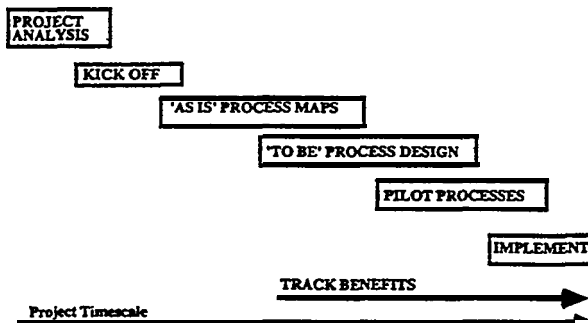


Figure 2 Typical project plan for a transformational change program

## Change and Teams

The process for delivering a program of transformational change must rely on the use of improvement teams to tap into the wealth of knowledge and expertise that lies dormant in almost all organizations. Teams are also the most effective way of developing the involvement and commitment at all levels of the organisation that are essential for making the change happen and 'stick' (see Figure 3).

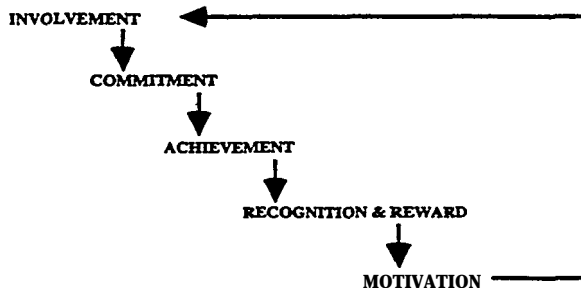


Figure 3 Positive Feedback Loop

Managing change requires that the management of resistance to change is successful. The agents of change must be skilled in applying established techniques that minimize resistance and have the interpersonal skills to apply them appropriately. Multi-level, multi-functional teams are essential in this context and particular attention must be paid to setting clear expectations of the goals to be achieved and the new behaviors that are expected to be displayed. The key objective must be to establish a critical mass of 'believers' or 'champions' to win over the majority who will be willing to comply with the change.

A central 'Change Team' is almost mandatory if the necessary enthusiasm and pace of change are to be sustained over an extended period. With appropriate guidance from the central team a large number of staff can quickly be equipped to apply a wide range of tools and techniques to achieve their goals. In addition to the established Total Quality tools these can include

- Structured problem solving,
- Process flow analysis,
- 'Day in the life of 'studies (DILO),
- Responsibility charting,
- Meeting management,
- Coaching and Feedback and
- Benchmarking.

## Investment in Change

It is almost a truism to say that the greater the investment that is put into the change process the more certainty there is of achieving the desired result of lasting change; the effort must also be carefully directed.

For a variety of reasons the case studies have involved the investment of significant amounts of management and staff time. The use of external consultant input was in each case relatively small and used primarily in a facilitation role to ensure that the projects were kept on track. In each case study the primary drive came from the companies' managers themselves. To illustrate this point the staff input at each of the case studies is summarized below.

**DML** The core AQAP team was made up of the Operations Director, Quality Manager and three consultants. In addition there were around thirty staff assigned full-time on producing operating procedures. All managers were expected to lead the training of their staff in the implementation of new procedures and to take part in the compliance checks of their peers. Management briefings punctuated the whole period.

**Swan Hunter** Eight directors and three General managers forming the Total Quality Board met bi-monthly over the period. The Steering Group met monthly and involved twelve General Managers. There were 36 facilitators from 22 departments who met bi-monthly in addition to their locally based activity. However those listed above were expected to devote



some 5-1070 of their time to the TQM program. A consultant was engaged part-time for around 18 months.

**Marine Projects** The BS 5750 steering group met fortnightly for around two hours to assess progress and to resolve major problem, it was made up of the eight most senior managers. Sub-teams from each department spent around half a day per week mapping and devising new procedures in the period up to accreditation. The operation of the performance measures process involves managers and first line supervisors in ongoing weekly Plan-Do-Review meetings lasting around half an hour; meetings between shop managers and the Production director are on a monthly basis and last around one hour.

The staff input required at any particular site will be shaped by the unique characteristics of that organisation's change program. Investing in change is primarily an investment in people.

### Quality Management Systems & Total Quality

Experience suggests that there is a part for both Quality Management Systems and Total Quality Management to play in a transformational change program. ISO 9000 can be a good vehicle for establishing control over the business as a precursor to more radical process improvements. The ISO standard is, after all, simply a template for good business practice; it must never be seen as an end in itself or just as a marketing tool.

Equally the concepts, tools and techniques of Total Quality can provide a sound basis for structuring the business process improvements that are required to deliver performance improvement now and into the future.

### CONCLUSION

It is hoped that this paper has demonstrated through the case studies that appropriate implementation of quality management systems and Total Quality Management can contribute significantly to the improved performance of a complex business such as shipbuilding. Moreover they have a place in the framework of any transformational change program that United States shipbuilders must implement if competitiveness on a world scale is to be achieved.

There is a window of opportunity for the shipbuilders of the United States to take advantage of the forecast upturn in the world's shipbuilding market. If business performance levels can be raised by a significant but achievable amount, and exchange rates remain at their present levels, it should be possible to capture a large enough share of the orders available to ensure along term and profitable future for a substantial number of the yards currently in operation. To do so will require that the lessons available from companies

with a similar background are learnt quickly. The need is to welcome and embrace the opportunity for transformational change as the starting point for a holistic approach to realising a step-change in business performance.

### ACKNOWLEDGEMENTS

The authors would like to thank Ewan MacLachlan, Operations Director of DML, and Chris Gates, Production Director of Marine Projects, for their permission to prepare the Case Studies and for their advice on the content. The help and support of their colleagues in AIMS, in the preparation of this paper, is also appreciated greatly. The authors also wish to state that the views expressed are their own and do not represent the views of any of the organizations mentioned in the paper.

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# The Product Model as a Central Information Source in a Shipbuilding Environment

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## ABSTRACT

In a shipbuilding CAD/CAM system a product model is successively built up during the design process, with geometric as well as non-geometric information. In parallel with the design process, the model is further extended with work preparation (in some countries called production engineering) information e.g. definition of building strategy and definition of the assembly structure.

Information needed for part fabrication can be derived from the model, such as drawings, parts lists and information for numerically controlled (NC) equipment. When work preparation definitions are combined with a product model, the information needed for assembly parts lists, assembly drawings, etc. can be derived from the product model instead of being created manually.

Use of the product model concept, systems based upon it and procedures implementing it in an organization will allow a reduction of costs and an increase in productivity and competitiveness.

## INTRODUCTION

### Background

Ships and offshore structures are often built in short series or as individual made-to-order products. The high complexity of the products implies an intensive design and planning process, where many tasks have to be performed in parallel. Often, manufacture of one part of the product is going on at the same time as the detailed design of another. The need for higher efficiency and shorter delivery times means that the number of overlapping activities increases and the process becomes more and more complex. In addition to this, there are numerous design changes which are introduced very late.

A new buzz word has been introduced in some industries to describe this situation: "Concurrent Engineering." Even if the term is new, the situation is

not new to the shipbuilding industry where people have been used to working with overlapping activities for many years. The ability to work in a controlled way with overlapping activities influences the efficiency of an organization to a large extent. A key element in increasing the overlapping is the management and control of the information flow.

In most cases at a shipyard, detailed design and production are performed within the company and under direct control of shipyard management. This gives a more or less unique possibility to find efficient ways to handle information flow and to transform potential information handling problems into an information handling skill, creating a competitive advantage.

Shipbuilding has been characterized as "A process where you, from rather simple parts, assembled in a very complex way, produce highly sophisticated products: which is a good description. It is important to produce parts with enough accuracy, but the real challenge is to manage and control the design and assembly process to gain efficiency and short delivery times.

After the political changes in eastern Europe, new countries will emerge as players in the commercial shipbuilding market. Other countries, formerly concerned with building mainly navy vessels, will enter the new building business and new developing countries, especially in the far east, will enter the market as shipbuilding nations. In addition, the present major players will reinvest to maintain their position. All these changes will lead to an increased shipbuilding capacity and a very competitive market situation.

Investments are already under way in many countries in shipyard facilities and modern equipment, such as robots and robotized production lines. These investments are combined with changes in working practices as well as training of personnel to reach an optimal solution. A key element of being able to maximize the return on these new investments is to ensure that the information systems that drive them are optimized for the needs of the business and closely integrated into the new process.

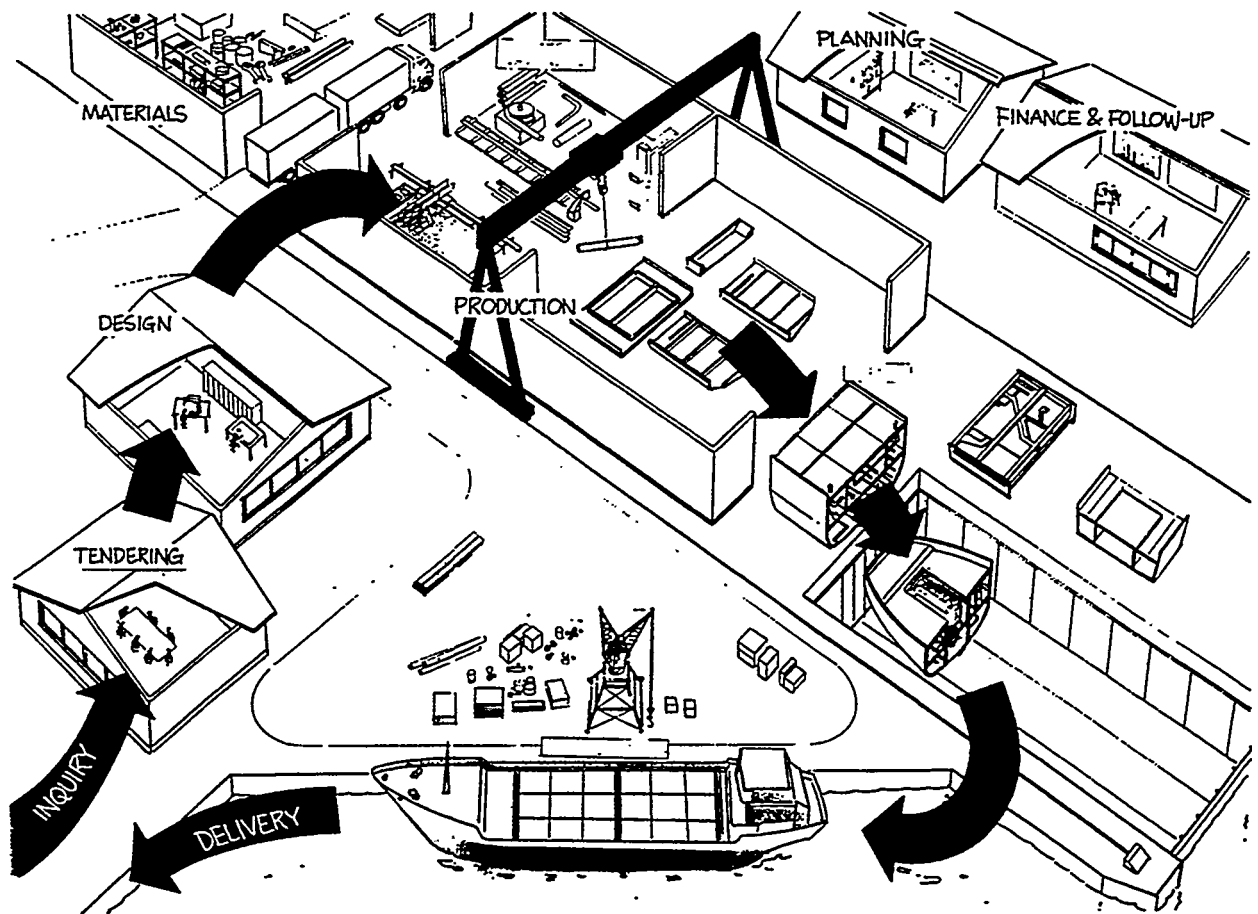


Figure 1 The Shipbuilding Business

### The Shipbuilding Business

The building of a vessel in today's world is an extremely complex business. In a simplified way, the main activities are shown in figure 1 and summarized below.

**Tendering.** Tendering is the activity where the initial design is agreed upon between the owner and the builder, together with a price and delivery time as part of the contract. The build strategy is defined. Decisions during this activity will highly influence the final cost for the contract.

**Design.** Design is the activity where initial design is further developed into a detailed design, assembly sequences are defined according to the build strategy and production information is created for production.

**Production.** In the production activity, the information created during detailed design is used to build the vessel. Production is usually divided into three major steps. The first step is parts manufacture where piece parts of different types are manufactured from raw

material. The second step is assembly where piece parts successively are put together to low level assemblies which are put together to higher level assemblies and so on until the final product is assembled. Finally in the commission stage the product undergoes tests and trials.

**Planning.** Planning is the activity where project plans are developed and monitored. Plans should be made for all activities and refer to the build strategy.

**Materials.** The materials activity supports design and production with all aspects of material control from purchasing to issuing of material from stores.

**Finance and Follow up.** In the finance and follow up activity all aspects of monitoring and control of finance, for the company and each project are handled.

**The Information Flow.** Starting with inquiry and ending with delivery, the shipbuilding business process involves a number of departments all generating and exchanging an enormous amount of information. This situation can lead to errors, duplication of work and delays when waiting for information. The net effect can be a very inefficient business.

One of the tasks of shipyard management' is to create an information flow solution specifically designed for this industry, to ensure that the organization is as efficient as possible in the shipbuilding process.

### Key Factors for Efficient Shipbuilding

There are a number of key factors which are related to information flow which have a major influence on the efficiency of ship production. These are listed below

**Design for Production.** Design for production ensures that the design can be easily produced and also reduces production manhours for the product. A well thought out build strategy describing how the vessel will be built must be developed, in parallel with early design activities, to ensure that the detailed design is best suited to the production facilities. In this way design for production can really be made to happen.

**Early Unit Breakdown** By deciding the build strategy and hence the major construction units (or assemblies) early, further design can take this into account to ensure that the units can be easily constructed through each assembly stage and that the necessary material can be ordered and marshalled to meet the building program.

**Prefabrication.** By maximizing the level of prefabrication, more work can be carried out at an earlier stage in the building process. When work can be carried out in workshop conditions as opposed to a building berth, the cost of the work is reduced.

**Preoutfitting.** By installing outfit items on hull assemblies and sub assemblies before the ship's hull is erected, the cost of outfitting can be reduced.

**Complete and Consistent Production Information.** Production information specifically created for each stage of manufacture can improve the efficiency of the operation as all necessary information is in one document and workers do not have to search for information. Consistent information along with proper accuracy control ensures that when manufactured items are joined at later stages in the building, they fit together correctly. These items can often be from different application areas, such as hull and pipe.

**NC, DNC and Robotics.** The use of numerically controlled (NC) equipment and *robots can* reduce the labor costs for items of work. It is important to be able to create the control information for these **machines** from the product model to be able to respond quickly to changes in the building program and design.

**Quality Control.** The control of quality or accuracy at each stage of production can reduce rework at later stages.

**Material Handling.** The efficient handling of material information, from initial specification through

detailed definition, purchasing, receiving, issuing and finally invoice clearance, is influenced by many departments. Shipbuilding is to a high degree an assembly process. If material handling is performed well this can have a major influence in the elapsed time and manhours for a project.

### The Challenges of Today

The challenges of today are to use systems and procedures for information handling that will lead to reduction of costs and increase in productivity. It is important to have the above key factors and special conditions in the shipbuilding industry in mind when evaluating the total information flow. To simply computerize the existing manual routines will not give as much benefit as taking the opportunity to streamline the information flow where possible, and to adapt the organization and way of working to the new tools and methods available.

The information flow traditionally consists of technical and administrative information in the form of documents, drawings, parts lists, etc. An alternative approach is the product model concept, where a database of information about the product is stored in a structured way specialized for the industry. The implementation of a product model concept is vital for the ability to optimize the key factors above.

### THE PRODUCT MODEL

The product model contains non-geometric as well as geometric information. Examples of non-geometric information are connections and dependencies between objects, such as topology, and characteristics about objects, such as material code, weight, surface treatment, energy consumption and flow capacity. It would be more proper to call the model a **product information model** to stress the difference between this information based model and a geometry or graphics based model of a product. However, since product model is the commonly used term, it is used in this paper.

When developing the layout of a complex area like an engine room there are frequent needs to analyze the arrangement in different views, to make sections and projections to verify clearances, etc. To do this with manually produced drawings is a heavy task when all sections and projections must be updated as the process goes on. For years, many shipyards have used plastic models as a tool to solve these problems, sometimes as a complement, sometimes as a substitute for manual drawings.

The product model is based on shipbuilding information objects. The content of the objects is

displayed as diagrammatical information, in a 2D drawing form or as a 3D graphics view depending on the stage of design. It is also displayed in lists and reports. All these views of information in the product model are illustrated in figure 2.

The graphical representation is only generated when it is needed, e.g. for viewing a model or creating a drawing. In this way, the graphical representation is generated as a symbolic, 2D or 3D representation, as indicated in figure 2, depending on the needs at the time of generation. The information stored in the objects is the primary information. The graphical representation (the view or the drawing) is secondary and generated by the visualization system. By handling the objects as the primary source of information, rather than the graphical information, the flow of information in the design process is streamlined.

The focus on shipbuilding information objects supports the integration of information. Each project should have a single model containing the information

for the whole project. Hence it is not necessary to link a work session to new files or drawings, or copy files to new sessions. When new model items are ready to be accessed by others, they are instantly available to all users within disciplines and across disciplines (e.g. hull and outfitting).

The building of the product model is a refining process that begins when the first product information is registered. This building process simply starts with an equipment item name and its function. This equipment object is refined during the design process. For example, when its system connections become known, they are added as well as its compartment location. Similarly, a symbol representation for use on a diagram and the 3D graphical information from a manufacturer's drawing can also be added. The principle is that once *some* information is known, it should be registered for use in later stages of design with easily refined information.

This approach also means that drawings and reports are extracted across a whole project by any selection criterion independent of how the data was created.

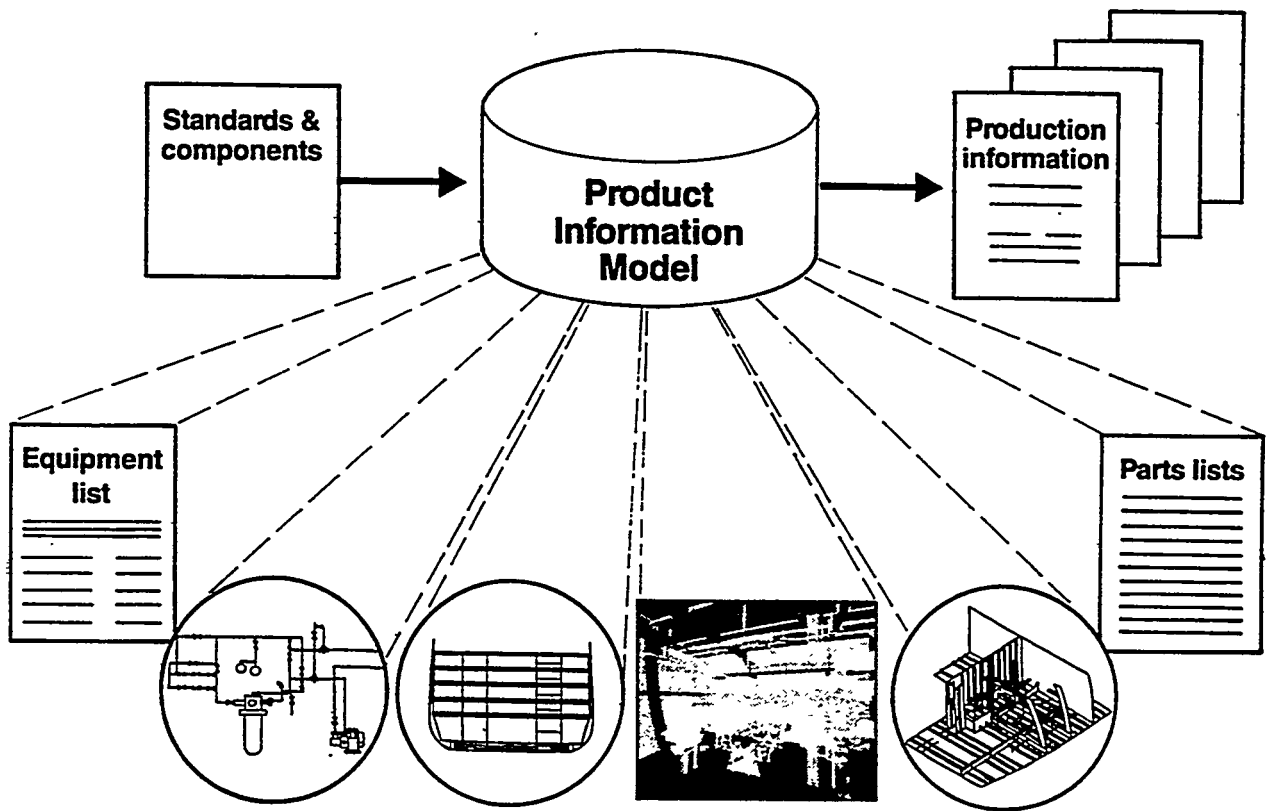


Figure 2 The Product Information Model

## THE SHIPBUILDING CAD/CAM SYSTEM

*The shipbuilding CAD/CAM system is a system designed to meet the requirements from design and production in shipyards as opposed to systems aimed for mechanical design that are generally referred to simply as CAI/CAM system. To be efficient, a shipbuilding CAD/CAM system must be based on the product model concept and address all phases in the design process in such a way that information from one stage can be used in the next*

The shipbuilding CAD/CAM system has powerful functions to define the shipbuilding objects and the relations between them in the product model. It supports designers in their work and helps them to communicate with colleagues in their own discipline and in other disciplines.

The building of a product model starts at the initial design stage, when the major components are chosen and the pipe and cable diagrams are developed. The topology of the diagram, the selection of components and the sizing are all essential to the model, even if they are presented in a 2D diagram only at that stage (see lower left part of figure 2).

During design the model is refined to a detailed level. Functions support the automatic or semi-automatic definition of e.g. stiffener endcuts and cutouts in plates. Brackets are defined by type and the system finds out the shape, internal stiffening e.t.c. depending on the environment. Cables are routed by semi-automatic functions.

A product model based system must understand what the different parts of the model really represent, and be able to interpret the rules and restrictions connected to each type of object. For example, to produce bending information for a pipe, or to check if it is at all possible to bend a certain pipe using the machine tools available in the workshop, the system must be able to distinguish pipes from other cylindrical objects that may look like pipes. Other examples would be having the ability to identify the difference between a bend and an elbow, between a prefabricated weld and an assembly weld, or investigating the surrounding structure of a pipe connection, where the system has to know which objects are pipes, stiffeners, seams, valves, etc.

The philosophy of a product model based system is that the information in the product model is the basis for the design and production process, and contains all technical product definition data. The different views, sections, projections and other information that build up the drawings are derived from the model. In this way the compatibility between different drawings is automatically secured. There is no longer a need to

restrict the number of views to evaluate a design because of the amount of drawing work. In such a system the drawings are not the primary information source.

Rules to control and check the different objects, depending on their properties, are defined. It is important to check the objects in the model directly at design time for production restrictions. Then an error is trapped at the source and not when it has created a problem in a workshop. Examples of checks are dimensional restrictions, shape restrictions (e.g. curve radius, possibility to use pipe bender), possibility to use welding equipment and interference checks.

In shipbuilding, numerical methods have been used for a long time to cut steel plates. The geometry and the marking information for all plate parts can be automatically created based on a product model.

The same process is applied to the handling of stiffeners and pipes. Information about stiffeners and pipe spools is automatically retrieved from the product model. The stiffeners are nested onto standard lengths of bar or shape material if applicable. Pipe sketches including parts lists are produced for each pipe spool. Whether a shipyard has chosen manual prefabrication or a fully automated line production, the relevant information can be retrieved from the product model.

Production information and setup information for jigs and different kinds of templates, quality control support, etc are also automatically derived from the product model.

The product model based system allows a user to automatically produce the many different types of production information needed to build a ship efficiently. Specialized production information creation programs speed up the creation of production information and provide a consistent and efficient type of information for workshops.

The quality of the information in the product model is an essential part of the total quality of the product. The product model must be included in the quality work-program in a shipbuilding company. In that process it can offer possibilities in judging the quality itself and in monitoring progress.

It is a strategic decision to use a product model and a system based on such a model. The information in the model is a common resource in a company and an important source of information in the exchange with the administrative functions of the organization.

## WORK PREPARATION

During the early phases of design the product model is looked upon as a set of systems. During the detailed design phase the model is also looked upon as

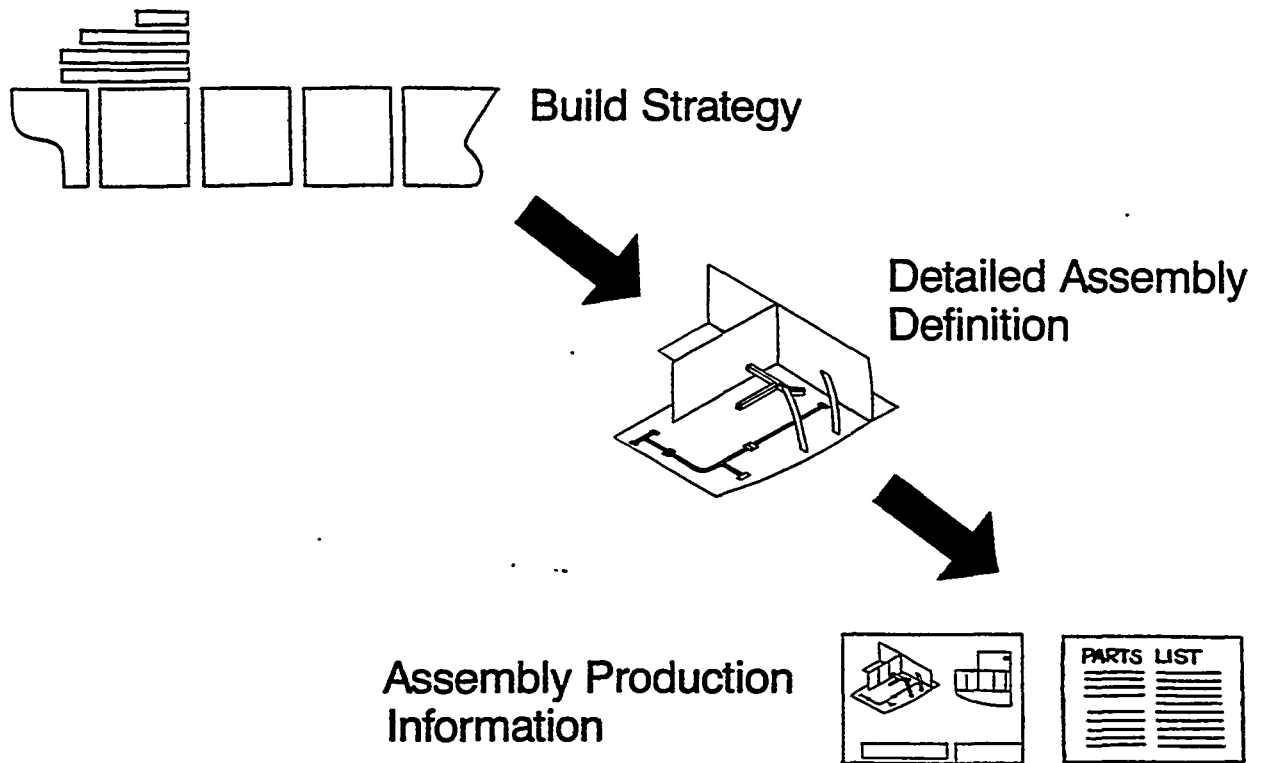


Figure 3 Work Preparation

subdivided into zones or compartments. These two views of the model are supported by the shipbuilding CAD/CAM system.

During production planning and production the product is looked upon as subdivided into a set of assemblies and assembly sequences. These definitions and this third view of the information are integrated into the product model and used by software supporting the work preparation (or production engineering). The combination of a shipbuilding CAD/CAM system and functions for work preparation forms a *shipbuilding CIM (Computer Integrated Manufacturing) system*. This approach is an efficient alternative to a traditional implementation of a Product Work Breakdown Structure.

Work preparation starts with definition of the build strategy. Later the detailed assembly definition is added. Using this information structure the assembly production information is extracted based upon information from the product model. Work preparation is illustrated in figure 3.

The build strategy is defined in parallel with initial design. It is a top-down subdivision of the product into high level assemblies as shown in figure 4.

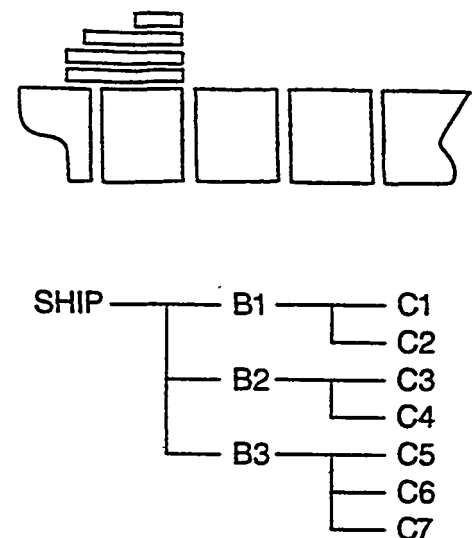


Figure 4 Build Strategy

The detailed assembly definition (see figure 5) is made bottom-up. Parts are selected to form subassemblies, which in turn are combined to next level assemblies and so on until the top-down definition in the build strategy is met. Interactive graphic methods support the definition of the detailed assembly structure. Thus, it is rather simple to select and edit the proper structure of objects for each step.

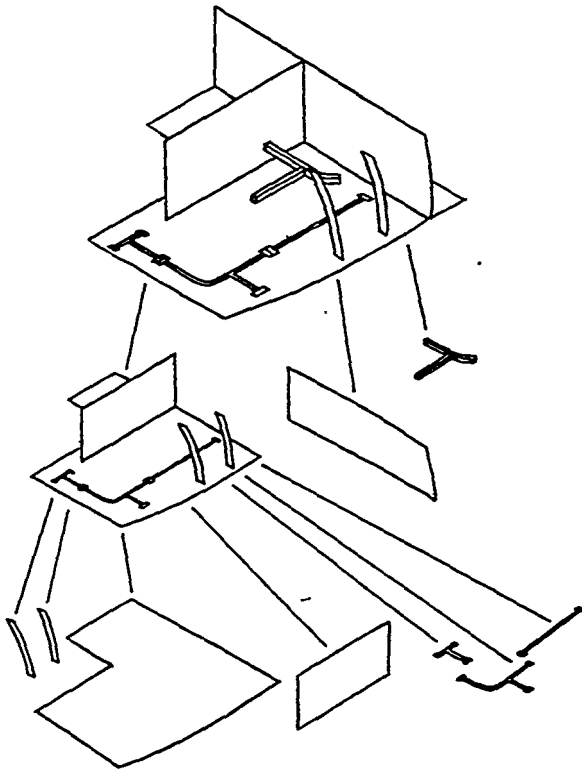


Figure 5 Detailed Assembly Definition

Traditionally, production drawings were just a refinement of the design drawings. The prefabrication information (plate part geometries, pipe spool details, e.t.c.) was obtained from these drawings which were also used for assembly purposes. Such production drawings and their parts lists usually showed the whole arrangement. Consequently the different assembly phases could not be distinguished.

When using a product model as the basis for drawing generation, it is easy to present one *set* of views from the model suitable for the designers, and another suitable for the production people.

Based on the assembly structure, drawings and parts lists are produced reflecting the assembly sequence (see figure 6). The information is produced at a late stage and is easily updated according to a change in the

design or the assembly structure.

The assembly information is packaged in a way that it contains relevant information for each stage in the process. It could be assembly of steel items, outfitting items or a combination of both, i.e. assembly of composites. All of these specialized drawings can be rather simple since they will be used for one purpose only. Detailed information is on the drawings only where it is needed. All information, from the prefabrication drawings to the last assembly drawings, is consistent since it is being produced from the information stored in the product model.

Normally, the production work is split up into workshop station sequences and/or work *operation* sequences for allocation of resources and scheduling purposes (job routing). As a further step in the use of a product model and integration with planning systems, there is a potential to create much of this information from the product model as well.

Parts lists are the fundamental source of information on material to be used. Traditionally the parts lists were produced manually during or after the drawing work. However, the designers already enter a lot of the parts list information into the product model during the design work. It saves work to extract the parts lists from the product model and then transfer the complete information to other areas, such as the materials system.

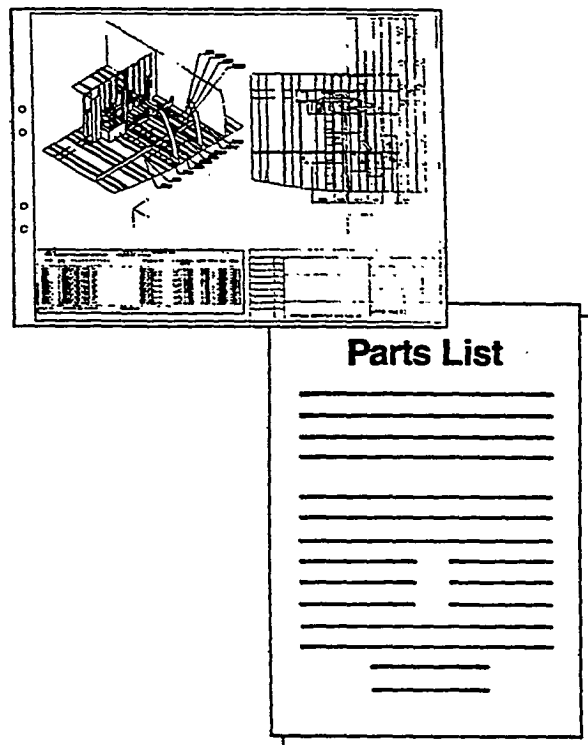


Figure 6 Assembly Production Information



## AUTOMATION

Automation of shipyard production means two things: preparing information needed for the production process automatically and making the process itself automatic.

In preparing information automatically, savings in manhours can be achieved as pointed out above. Since very little time is necessary for preparation of the information, the lead time is short which allows for late modifications of the assembly process or the design without spending extra hours on replanning and redrawing.

When burning tapes were first punched, then verified by drawing and then sent to the workshop, in most cases long before they were going to be used, there was a lead time of several days for changing a tape. Now burning information can be produced and verified by the CAM system and stored electronically together with the drawing and other necessary information. A workshop can then request the information when it is needed. The lead time for this cycle is very short.

There are different philosophies for fabrication of profiles: using shapes as raw material or building them from plate parts. Whatever method is used, the necessary information is found in the product model: the material type, cut outs, profile identification number, lengths, shapes etc. Several implementations of production lines for profiles exist today.

The information in the product model can also be used for marking. When and how marking should be performed is intimately linked to production methods and tolerance control.

Work shops, such as pipe shops, can be run as separate units within a shipyard. When the product model for a pipe exists and is approved, the information for each pipe spool can be made available for the workshop together with drawing information and information on when and where it is needed.

Normally, pipe information is released by block or assembly. Pipe shops prefer to operate by dimension. Using the product model this is not a problem.

The product model contains the following information for the pipe shop:

- pipe material,
  - pipe length,
  - bending information,
    - component information,
    - component orientation,
    - welding information,
    - surface treatment and
    - spool identification number.
- A pipe shop planner selects the information on such

attributes as dimension, quality, material availability and time for delivery to the assembly shops, and plan the work in the best possible way. Production documents are produced locally when needed. The use of this method was one important element when Kockums Shipyard, 10 years ago, reduced 3 shifts to 1 in the pipe shop!

With the knowledge of the assembly sequence, drawings and parts lists can be made automatically, at least to a great extent. It has been discussed above.

## PRODUCTION LINES AND ROBOTS

Many different types of production lines and robots exist or are part of on going development projects. All of these different types of equipment can get the necessary product information from the product model.

For example, a welding robot can get the nominal welding trace and the type of weld from the product model. The model can also provide the necessary geometry for interference control (if necessary).

It is important to find methods to define the movements of the robot based on information in the product model and on standards, patterns and macros. Otherwise the necessary information for robot movements and the simulation of it has to be defined from scratch. If so it is likely that the tool path definition and the movement control will become a bottleneck with a lot of intensive manual work involved. With a careful selection of methods and standards, the product model can be used for analysis of the context minimizing the manual interactions.

Production lines for profiles have been mentioned above. These lines are often equipped with robots for the cutting operation. Panel lines equipped with multiaxis DNC machines have been installed in several shipyards. These are used to produce panels made from plates and profiles. Cutting these panels with continuously varying bevel angle across welds is a complex problem. The information needed is extracted from the product model.

## RESEARCH

The importance of the product model concept is internationally recognized, and a lot of work has been and will be assigned to the area. STEP, meaning Standard for the Exchange of Product Model Data, is an informal name of what is expected to become an ISO (International Standardization Organization) standard. The aim of STEP is to define a neutral (vendor independent) format to exchange product models between companies or users within the same company, using different systems.

Within the area of shipbuilding, NIDDESC (Navy Industry Digital Data Exchange Standards Committee) in U.S., ESPRIT (European Strategic Programme for Research and Development in Information Technology) in Europe and others have had projects going on for many years. MARITIME (Modelling and Reuse of Information over TIME) is one of the ESPRIT projects presently working with these questions.

Projects from Europe, Japan, Korea and the U.S. working in this area were presented at ICCAS 94 (8th International Conference on Computer Applications in Shipbuilding). Interested persons are recommended to read the published proceedings (see References).

#### ADVANTAGES WITH A PRODUCT MODEL BASED SYSTEM (CONCLUSION)

In a product model based system the product model serves as the source of information for all activities. Lead time between activities can be reduced since all information released in the model will be immediately available for others involved in the process. This allows many designers to work in parallel. The approach

- supports the idea of working in zones,
- decreases the need for documentation on paper,
- decreases the amount of double work and copying and

- keeps the information consistent.

The net result is considerable savings in design time. The high quality and consistency of the production information also means that major benefits can be achieved in production. When the production information can be produced automatically, very little effort is required, once the design is made. This means that it can also be made fast which gives two benefits

- the production information can be made earlier to have an early start of production and
- the production information can be made just before being required so that late design developments and changes can be incorporated.

This means less rework and less information floating around with the risk of being out of date.

The benefits depend on many factors, but experience from shipyards shows reduced:

- time from contract to delivery of up to 30-40%,
- manhours in design and production up to 20-30% and
- cost for material.

In a paper (Bong, 1994) presented at ICCAS 94 the technical director at Daewoo Shipbuilding & Heavy Machinery Ltd., reported a reduction in the number of designers from 190 to 164 at the same time as the design period was reduced from 7.5 months to 5.5 for a VLCC ship. The reduction was a result of

implementing a product model based system.

Implementing a product model based system will also encourage the use of design and production standards.

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# The Influence of Integrated CAD/CAM Systems on Engineering for Production Methodologies in Shipbuilding

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## ABSTRACT

This paper discusses the influence of integrated CAD/CAM systems on engineering for production methodologies in shipbuilding, using the European, and particularly the Spanish, experience as an example. While traditional methods of ship production are ill-suited for today's international shipbuilding arena, approaches such as engineering for production can provide significant improvements to a shipyard's competitive edge, using concepts such as simple and repetitive modules; enhanced work organization; and transitioning, as the ship design matures, from a 'systems' perspective to a perspective of 'workstations and zones.'

CAD/CAM, as adapted for shipbuilding applications, can serve as a catalyst and a tool to implement engineering for production methods. Examples of this actually taking place can be found in European shipyards. Such shipyards have, for example, recognized the strength of the integrated CAD/CAM product model, which contains ship design and production information in a single product data base and serves as a resource to all levels of shipyard personnel during the design and production of a ship. Engineering for production has been greatly advanced in the Spanish shipbuilding industry with its adaptation of the integrated CAD/CAM approach. A particular case in point, illustrating the dramatic improvements possible, is a Spanish shipyard using an integrated CAD/CAM system.

In many cases, the successes of European shipyards in using integrated CAD/CAM systems may be directly translatable to the U.S. shipbuilding industry, with resultant improvements in U.S. competitiveness.

## NOMENCLATURE

CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
HVAC	Heating, Ventilation and Air Conditioning
NC	Numerical Control
PC	Personal Computer

## INTRODUCTION

U.S. shipyards, in their present efforts to become competitive in the world shipbuilding market, are seeking ways to increase productivity in the design and production of ships. Practically speaking, this means reducing ship design and construction schedules and costs. One important tool that may be used to reach this end is the engineering for production methodology. Engineering for production has

been in use for some years and is continuing to be improved. This paper will address one aspect of that improvement: the use of integrated CAD/CAM systems.

The paper is set in the context of the U.S. shipbuilding industry. While the discussion is relevant to shipyards of all sizes, an attempt is made to highlight the smaller and medium size U.S. shipyards, that is, those yards with fewer than 1,000 employees. The reasons for this are as follows:

- smaller and medium size yards are a focus of this year's Ship Production Symposium,
- many discussions of engineering for production and integrated CAD/CAM systems are not directed at the smaller and medium size yards,
- smaller and medium size yards stand to benefit from the use of engineering for production that is enhanced by integrated CAD/CAM systems,
- smaller and medium size yards often do not realize that this type of technology can be practically applied to their operations, and
- smaller and medium size yards form a significant part of the U.S. shipbuilding industry, as shown in Figure 1 (In the U.S. there are 29 yards with 250-500 employees, 13 with 500 to 1000 employees and 12 with over 1000 employees).

This paper is organized into the following sections:

- Engineering for Production Methodologies describes the development of the engineering for production concept and cites an example of its implementation;
- Integrated CAD/CAM Systems reviews the evolution of shipbuilding CAD/CAM, summarizes today's state of the art and provides an overview of the use of CAD/CAM in U.S. shipyards;
- CAD/CAM's Influence on Engineering for Production shows the common thread between CAD/CAM and engineering for production and describes the extent of CAD/CAM's influence; and
- Conclusions relates Spanish experiences to the U.S. shipbuilding industry.

## ENGINEERING FOR PRODUCTION METHODOLOGIES

### Development of Engineering for Production

Engineering for production was developed to help correct some of the inherent inefficiencies in traditional shipyards. Examples of these inefficiencies include the

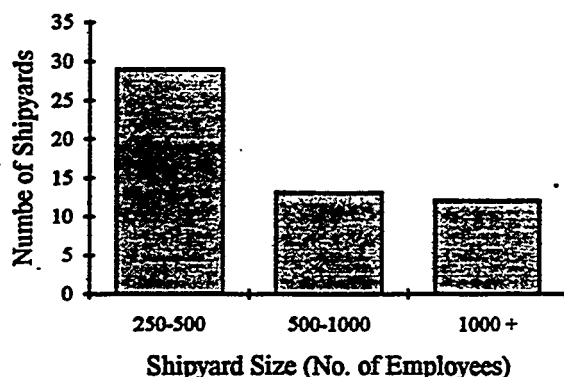


Figure 1  
Distribution of U.S. Shipyards by Size

following: lack of up-front procurement definition; separate departments and shops; a lack of horizontal and vertical communication; different definitions in different sectors of a shipyard of 'the design' and 'the build plan'; and the need for a large amount of rework during construction.

Engineering for production may be defined as a method to apply group techniques and interim product techniques to one-off products like ships." From the very beginning of the design process, the focus is placed on the end use of the engineering product. That end use is to help define the production of the ship. For example, the emphasis is not on systems (e.g., the structure) but rather on zones. The perspective is that of those who must produce the ship; the result of engineering must be a tool that the ship production personnel can use.

#### Spanish Shipyards' Approach to Engineering for Production

In the mid-1980s, after the second oil crisis, the Spanish shipbuilding industry was in deep trouble. Still reeling from the effects of the first oil crisis, this industry had fallen from a production level of over 600,000 gross tons in 1975 to under 100,000 gross tons in the middle to late 80s. The industry took strong action, including learning from the Japanese and from the research of the National Shipbuilding Research Program. One part of the Spanish yards' multi-faceted approach toward recovery was to adapt 'design for production integration,' the first three elements of which are listed below (Gutierrez, 1992).

- Establish a stepped process for the definition of the vessel with coordinated advancement of the design, planning and material management.
- Reorganize the structure of the technical offices according to the zone-per-stage principle and improve the quality of contract design.
- Improve the relationship between technical offices and production, procurement and planning departments.

Early results of the Spanish effort show promise, including a reduction in lead time while simultaneously improving accuracy of planning, and an increase in overall productivity (Gutierrez, 1991).

## INTEGRATED CAD/CAM SYSTEMS

### Evolution of Shipbuilding CAD/CAM Systems

The evolution of CAD/CAM systems in the shipbuilding industry has taken place in a short time span with respect to the present age of industrialized shipbuilding. Table I illustrates this point. While the birth of industrialized shipbuilding can be set in the middle of the last century, well over one hundred years ago, the birth of shipbuilding CAD/CAM can be dated from the early 1970s, less than a quarter of a century ago. Another point that this table makes is that CAD/CAM is increasingly becoming a capability not only of the big yards but of the medium and small yards as well. The table illustrates the trend from main frame computers to local area networks and workstation and PC hardware coupled with integrated software. Software on modern systems may include a single database, which facilitates the construction of a product model (a key ingredient for using CAD/CAM to enhance engineering for production).

The table shows the evolution of shipbuilding CAD/CAM in general; not every shipyard evolves through each of the steps of the process. Also, as can be seen in the results of a survey by the authors (summarized in a following section), a number of U.S. shipyards do not yet possess the computing capabilities of the '87-94' row of Table I. For

Y R	HARDWARE	SOFTWARE	END USERS/ COMPUTING POWER
1 9 7 2 - 7 8	Big computing centers. Main frames. Punched cards and alphanumeric terminals.	Independent applications. Sequential files. Batch processes.	Big shipyards. High computing level.
7 9 - 8 6	Medium computing centers. Midi/Mini computers. Alphanumeric terminals and graphic terminals.	Integrated applications. Medium level independent databases. Interactive processes.	Big and medium shipyards. Medium computing level.
8 7 - 9 4	Local area networks. Workstations. X-Terminals PCs.	Fully integrated applications. Single database. Interactive graphic processes. Open systems.	Big, medium and small shipyards. Low computing level.

Table I  
Evolution of Shipbuilding CAD/CAM Systems  
(adapted from Garcia, 1994)

them, obtaining a modern CAD/CAM capability can represent not just an evolutionary step but a quantum leap.

### CAD/CAM Today

A number of ship design CAD/CAM systems are available on the world market, including AutoSHIP, FORAN, HICADEC, HULLTECH, IMSA, NAPA, NAVSEA CAD-2 and TRIBON. The systems, or at least the modules which comprise the systems, have evolved over a period of years and are still being improved. While different systems focus on different aspects of CAD/CAM, they typically may include elements such as concept/basic/detail design, lofting, NC cutting and input to production robots. Recent development trends include further integration through product models, enhanced communication with third party programs, increased user friendly interfaces, and the extension of program capabilities into earlier stages or design and later stages of production (Ross, 1993). In addition, today's systems typically keep pace with the computer hardware industry, with its ever increasing computing power packaged in smaller and smaller machines. Thus, a program that needed a midi to function adequately several years ago may run today on a workstation or even a PC.

### CAD/CAM in U.S. Shipyards

A number of U.S. shipyards have at least some components of a CAD/CAM system. Some of the larger yards have systems that have developed in house; the smaller and medium size yards have systems developed by third party vendors. A recent survey conducted by the authors provides insight into this subject. The survey was conducted during July and August of 1994 and included a mail-out and follow-up phone contacts to U.S. yards that have 250 or more employees. Of the 54 yards contacted, 20 (37%) responded. The responses provide insight into the present and near-term planned use of CAD/CAM in U.S. shipyards.

Figure 2 shows the percent of responding shipyards in each category (i.e., 250-500, 500-1000 and 1000+ employees) which use or plan to expand or replace their CAD-capable hardware, such as a Unix network, a PC network or a stand-alone PC. The results from 'responding shipyards' are used in this and the following charts. This may not reflect the trend in all of the U.S. shipyards of that category, since not all yards responded to the survey (for example, suppose there were 25 yards in a category, 10 responded, and of those 10, 8 presently used CAD hardware. Then the chart would indicate that 80% of the yards in that category use CAD hardware). Also, while certain yards may either 'presently use' or 'plan to expand or replace', other yards may both presently use and plan to expand/replace CAD hardware. Thus, the results of present and planned are independent and their sum, for a given yard size category, may exceed 100%.

The results indicate that all yards in the 500-1000 employee category presently have CAD hardware and 75%

plan to expand or replace CAD hardware in the future. Next highest in present ownership are the 250-500 employee yards and the 1000+ employee yards (both 75%). 38% of the 1000+ yards have expand/replace plans, followed by 25% of the 250-500 employee yards.

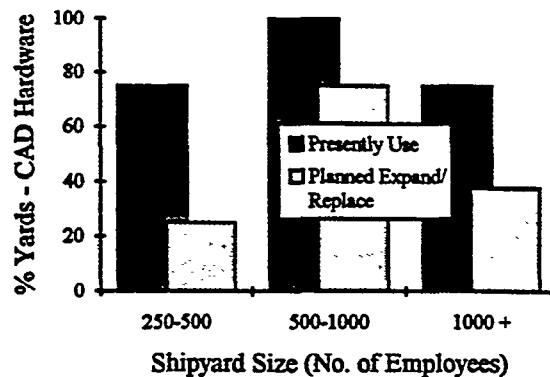


Figure 2  
Use of CAD Hardware by U.S. Shipyards

Figure 3 shows the percent of shipyards with presently installed or planned CAD software such as GHS, Fast Ship, or SHCP. The 500-1000 employee yards again lead, with 100% for present and planned use. The 250-500 employee yards follow with 38% present and 63% planned, and then come the 1000+ employee yards with 38% present and 38% planned expansion/replacement of CAD software.

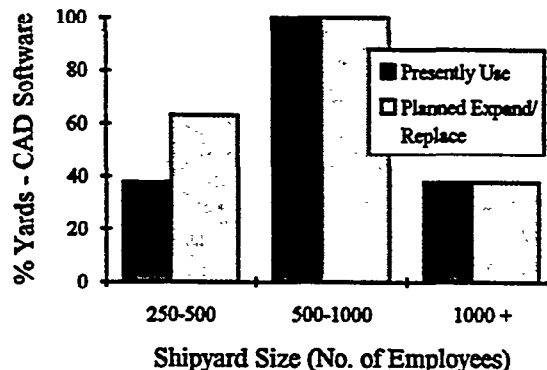


Figure 3  
CAD Software in U.S. Shipyards

Figure 4 shows the percent of shipyards with presently installed or planned steel production software, such as ShipCam, SPADES, or AUTOKON. In this case, the trend is completely driven by the size of the yard: the larger the yard, the higher the commitment to steel production software. Of the 250-500 employee yards, 13% presently use and 25%

plan to expand or replace steel production software. For the 500-1000 employee yards, the percentages are 50% present and 50% planned (the same yards). For the 1000+ employee yards, 63% presently use and 63% (a slightly different mix) plan to expand or replace this type of software.

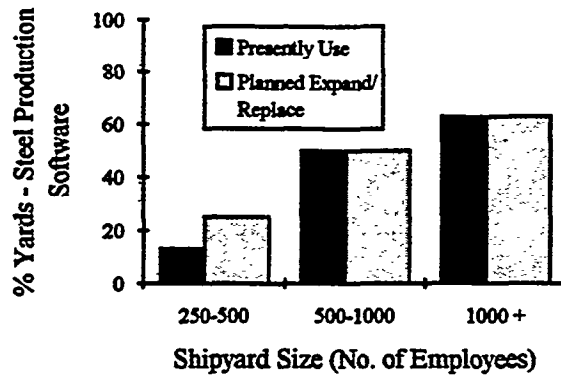


Figure 4  
Steel Production Software in U.S. Shipyards

Figure 5 shows the percent of shipyards with presently installed or planned drafting software, such as AutoCad, Microstation, or CADAM (not to be confused with CAD/CAM). For present use, the trend is dependent on shipyard size: 63% of the 250-500 employee yards presently use this type of software, raising to 75% in the 500-1000 employee yards and 88% in the 1000+ employee yards. For planned expansion or replacement, the 500-1000 employee yards lead (75%), followed by the 1000+ employee yards (38%) and then the 250-500 employee yards (13%).

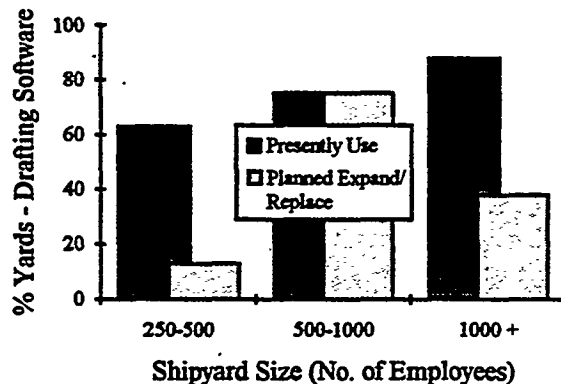


Figure 5  
Drafting Software in U.S. Shipyards

Figure 6 shows the percent of shipyards with presently installed or planned piping, HVAC or electrical design software, such as CadMatic, CSA or RAMP. The 1000+

employee yards lead in present and planned (50% present, 63% planned), followed by the 250-500 employee yards (25% present, 50% planned), and then the 500-1000 employee yards (25% for both).

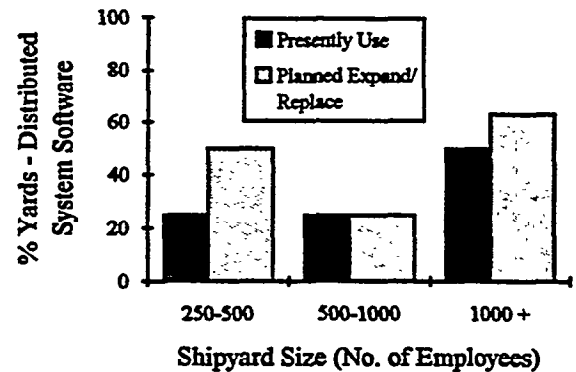


Figure 6  
Distributed System Software in U.S. Shipyards

Figure 7 shows the percent of shipyards with presently installed or planned CAM facilities, such as numerical cutting or robotic welding. The 500-1000 employee yards lead in present use (100%), followed by the 1000+ employee yards (88%) and then the 250-500 employee yards (25%). All of the 500-1000 employee yards had plans for future expansion or replacement, followed by 25% of the 250-500 yards and none of the 1000+ employee yards.

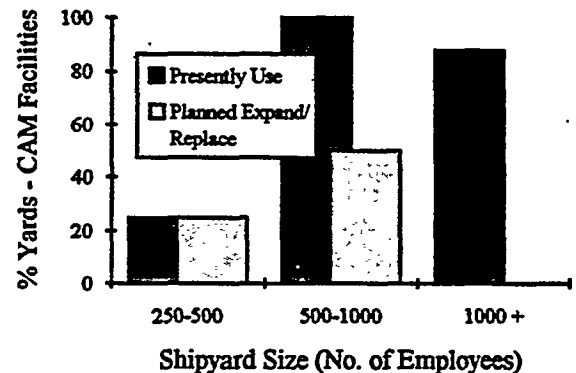


Figure 7  
CAM Facilities in U.S. Shipyards

Finally, Figure 8 shows the shipyards' preference for UNIX or PC computers. Since this was an either-or choice, the totals add to 100% except in cases where yards did not state a preference. The results show that PC computers are by far the first choice, having been selected by 75% of the 250-500 employee yards, 75% of the 500-1000 employee

yards and 75% of the 1000+ employee yards. UNIX systems were preferred by none of the 250-500 employee yards, 25% of the 500-1000 yards and 13% of the 1000+ yards.

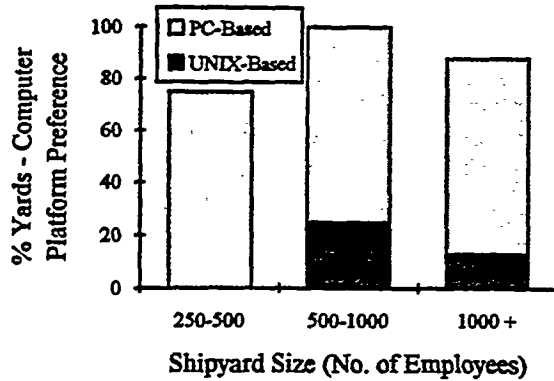


Figure 8  
U.S. Shipyard Computer Platform Reference

- From this survey, the authors concluded the following:
- The response rates to the survey are considered sufficiently high to establish general CAD/CAM trends in U.S. shipyards with 250 or more employees,
  - These shipyards are committed to CAD/CAM *persently and as part* of their planned acquisitions,
  - The interest shows by yards in all yards in all three size categories in CAD/CAM extends to all types of software and hardware addressed in the survey, and
  - PCs are preference above UNIX computer platforms.

#### CAD/CAM's INFLUENCE ON ENGINEERING FOR PRODUCTION

using CAD/CAM to enhance the effectiveness of engineering for production is not a new idea. It was well articulated by Lamb in 1986 when he recommended computers "be used to develop data such as a full-size

1986). The idea of such an enhancement ,was also part of the elements of their design for production integration plan were presented above. The forth element was to "Develop CAD/CAM applications to support information flows and to produce the required graphic and written information (Gutierrez, 1991)."

To define the influence of integrated CAD/CAM on engineering for production, one may first look for a common thread between integrated CAD/CAM and engineering for

the concept of integration. Integration is a dominant trend in concept Integration is also a dominant theme in engineering

for production, which after all, is integrating engineering into the production process.

Given this influence that integrated CAD/CAM systems have on

measured by the ability of integrated CAD/CAM to help realize the integration goals of engineering for production. This ability is one of the strong points of the better integrated CAD/CAM systems. Those systems can have significant

Significantly enhanced the yard's engineering for production methodology, as discussed below.

This privately owned shipyard, founded in 1924, is located in Valencia, Spain and presently has 800 employees

projects are shown inTable IL. This shipyard is proactive in

YR DEL	NAME	TYPE	TOTAL LENGTH (m)	DEAD WT (tonne)
1992	Crown Jewel	Luxury Cruise Ship	165	1800
1993	Crown Dynasty	Luxury Cruise Ship	165	1800
1993	Las Palmas de G.C.	Ferry	116	2650
1993	Sta Cruz de Tenerife	Ferry	116	2650
1994	Mar Almundena	Asphalt Carrier	121	9435
1995	(Car Ferry)	Ferry	153	3070

Table II  
Recent Ship Construction by Unión Naval de Levante  
(Adapted from Poblet, 1994)

methodology (which it labels 'production oriented design') and enhancing its CAD/CAM capabilities. Regarding production oriented design the ultimate aim is to drastically cut production costs through increased efforts in design and layout. Significantly, the tool that the shipyard views as **making this possible is CAD/CAM. On the personnel side, the shipyard is increasing training in the use of computers.** In-house staff are developing software, often in conjunction with software system suppliers. Also, efforts are being made to enhance communication between computer systems used for management and those used for design and production.

This shipyard has a CAD/CAM capability which has evolved into a comprehensive system Figure 9 shows the system's growth as exemplified by the increasing number of workstations. As reflected in this figure, **the computer was introduced to the yard in 1984, with significant growth every year since.** The shipyard is encouraged by the results of

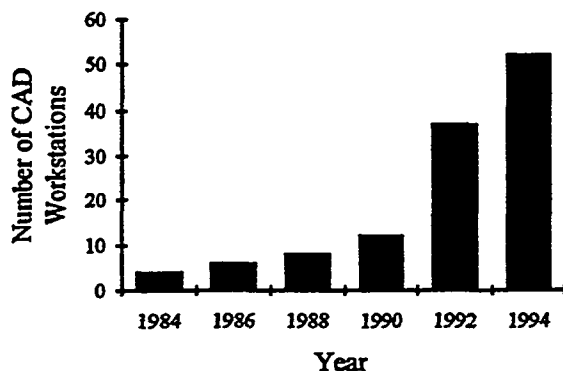


Figure 9  
CAD Workstation Evolution at Unión Naval de Levante  
(Adapted from Poblet, 1994)

implementing and enhancing CAD/CAM and points to the following improvements:

- Dramatic decrease in design time (e.g., 8 people working 6 months vice 21 people working 18 months to develop steel construction drawings),
- Decreased engineering time (e.g., in carrying out hydrostatic calculations by computer instead of by hand),
- Ability to quickly conduct what-if studies at the early stages of a project, and
- Ability to automate NC cutting of nested piece parts from steel plate.

A particular area where CAD/CAM has been implemented at the shipyard, with a corresponding influence on engineering for production, is piping design and production. Traditionally, piping design was conducted through the use of 2-D drawings, a plastic model, isometric drawings and, in the pipe shop, templates and manual checking. With the traditional approach, very little premanufacturing was carried out. Now the approach has been changed, radically enhancing how design information is developed and then relayed to the shop. With the present approach, the design is developed exclusively by CAD/CAM. Design information is provided to the pipe shop in the form of 'spools,' which contain only what is relevant to the piping and its associated valves and accessories. The spool includes on a single sheet of paper the drawing of the particular pipe with the geometry information and a list of materials as shown in Figure 10 (following page).

The transition from the traditional method to the use of CAD/CAM and spools is being carried out during the design of several ships. As each new ship is produced, the proportion of piping designed by CAD/CAM has increased.

That is, instead of relying on manual methods (without intervention of any CAD system), automated methods were used, including mixed 2D (CAD drawings; construction information gathered manually), mixed 3D (design with CAD model; construction information gathered with integrated CAD/CAM model), and complete reliance on an integrated CAD/CAM. This is illustrated by Figure 11. As shown in that figure, the machinery piping in *Crown Jewel* was designed almost exclusively by manual methods. With *Las Palmas* and *Mar Almukena*, proportionally more use was made of CAD/CAM, until with the *Car Ferry* (presently under construction), most of the piping design is through CAD/CAM.

## CONCLUSIONS

Much of the technology cited in this paper has been developed in the U.S., some of it through the sponsorship of the National Shipbuilding Research Program. The U.S. shipbuilding industry is accustomed to hearing how Japan

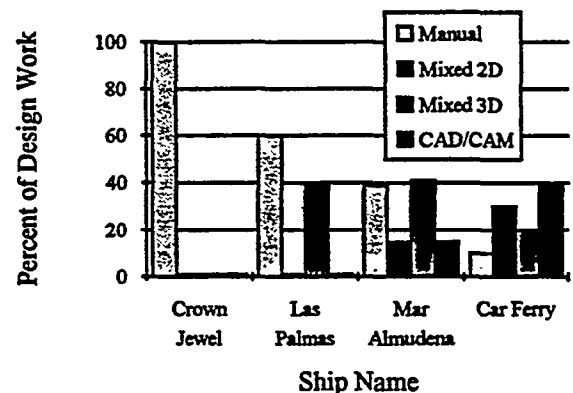


Figure 11  
U.N.L. Design Approaches for Selected Ships  
(From Poblet, 1994)

learns, uses and benefits from our technology. The Spanish have learned, used and benefited as well, and their example may be more appropriate for use in the U.S. The Spanish shipbuilders brought themselves back from the doldrums, just as the U.S. shipbuilders want to do. And part of their success is by understanding and enhancing the role of CAD/CAM in engineering for production.

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## Past and Present Concepts of Learning: Implications for U.S. Shipbuilders

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### ABSTRACT

The experience curve has been used as the model of learning within manufacturing for nearly a century, and has been used as a basis for predicting future performance and for setting performance targets. First, a summary of the experience curve and its underlying premises is given. Then deficiencies in experience-based model of learning are presented. The case is made that an organization that attempts to compete on the basis of incremental improvements on past experience, as represented by past competence and number of units produced, will not be able to compete with the most competent competitors that are using market-driven performance targets and conscious learning and problem solving methods to drive innovation. Two actual examples of learning outside the paradigm of the experience curve are discussed. One method of measuring present learning rates for individual processes is presented. It is concluded that U.S. shipbuilders need to look outside the experience-based model of learning, and the associated idea of series production of standard ships, toward conscious methods of learning and problem solving in order to become competitive in the commercial shipbuilding market.

### SUMMARY OF THE EXPERIENCE CURVE LEARNING MODEL

The traditional experience curve model of learning and improvement is founded on the presumption that individuals and organizations learn and performance improves solely as a result of experience gained through repetition of similar work. Along these lines, a recent *Journal of Ship Production* article, entitled "The Effect of Learning When Building Ships," (Erichsen, 1994) defined learning as, "...the ability to do the same task faster and better as *experience is gained*..." (emphasis added). The experience curve function (Thurstone, 1919) can be represented as:

$$y_n = a * n^b \quad (1)$$

where  $n$  is the sequential production number of the unit of interest (example: tenth unit produced),  $Y_n$  is an objective measure of performance, such as cost or labor hours per ton, for the  $n$ th unit produced,  $a$  is the value of  $y$  for the first unit produced ( $y_1$ ), and  $b$  is an exponent less than one that is usually derived from regression analysis of historical data. Figure 1 shows a typical experience curve with a first unit cost,  $a$ , of 100% and  $b = -0.074$ . This curve gives a second unit cost of 95% of the first unit, a third unit cost of 92.2% of the first unit, down to a cost for the twentieth unit of 80.1% of the first unit.

Some of the reasons why experience can improve performance are as follows.

- Repetition - People and organizations learn to do a task or project better and in less time if the task or project is repeated. This is the basis of the old adage, "Practice makes perfect."
- Specialization - If a job is broken into specific specialized tasks, and then individuals or groups are assigned to each specialized task, (as opposed to the entire job being assigned to a single individual or group) each individual or group can then repeat their specific task continuously, assuming continuous demand, without interruption from other dissimilar types of work and thus learn more effectively and quickly.

While some causal relationship exists between experience, in terms of the number of units produced, and an organization's level of competence and rate of performance improvement, there are problems with associating all learning and related performance improvement only with experience. Before using an experience curve as the basis for predicting future learning and performance improvement these problems must be recognized and addressed.

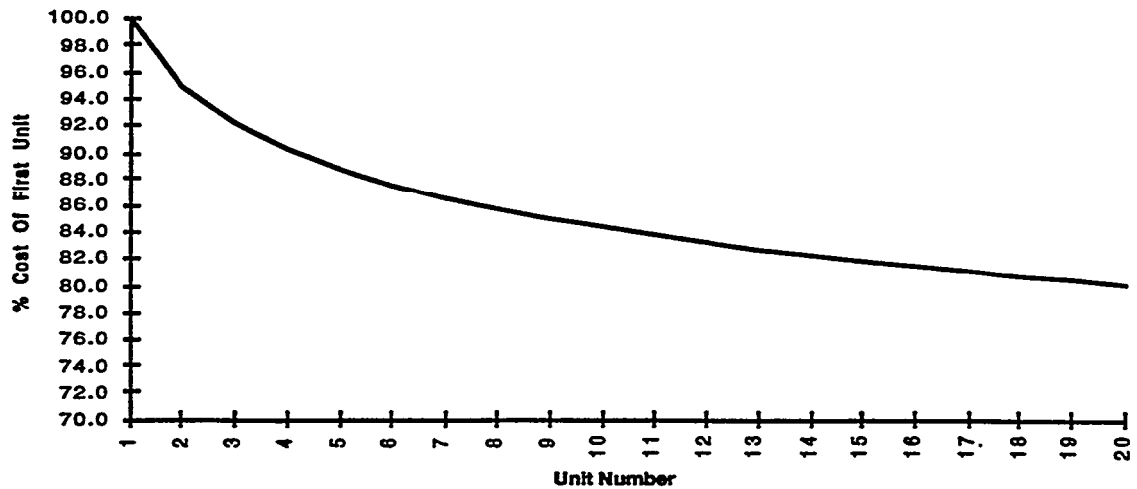


FIGURE 1. TYPICAL EXPERIENCE CURVE,  $a = 100$ ,  $b = -0.074$ .

#### DEFICIENCIES IN THE EXPERIENCE-BASED LEARNING MODEL

First, the experience-based model of learning implies that learning can only occur as a result of series production of identical, or at least similar products. According to this model, an organization's capability in producing a product is only a function of its capability when it started to produce the product and the number of products it has produced since it started. Likewise, the organization's rate of learning over time is solely dependent on the rate these products are produced. This would imply that two organizations that started with the same amount and type of experience, and that have produced the same number of a particular product, must now be equally competent at making these products, and must be learning at exactly the same rate per unit. This would also imply that of two organizations that started with the same amount and type of experience, the organization that has built ten units of a product must be more competent than the other organization that has built only two units, and the organization that has built two units must be learning at a faster rate per unit. However, an examination of business performance in many markets shows that these types of relationships do not necessarily hold; that future performance is not necessarily and absolutely dependent upon past production volume and performance. There are other factors that influence competence and learning rate. Some examples of this will be given in a later section of this paper.

Secondly, the experience-based model of learning only looks backward in time, and thus ignores market forces that dictate the future levels of competence and performance improvement rates that will be required to remain competitive. The relevant manage-

ment questions that need to be answered are, "How good are we now?", "How good are the best competitors now?", "How quickly will the best competitors improve over time?", "At what rate must our performance improve overtime in order to become or remain competitive?" The answers to these questions relate to current performance and future market-driven requirements, and have nothing to do with number of units produced in the past or how well the organization performed in producing those units. For example, if a shipbuilder wishes to be competitive building VLCC's in the commercial market two years in the future, that shipbuilder must be capable of at least meeting competitors' anticipated prices, delivery times, and levels of quality at that future time regardless of whether the shipbuilder has built zero or twenty VLCC's in the past. In a competitive shipbuilding market or any type of competitive market past performance is irrelevant, and price, delivery time, and quality performance, as well as rates of improvement required in each of these areas, are established by the most competitive producers in the market. What must be dealt with is current and projected performance of the organization and its most competent competitors. The market-based approach to establishing performance improvement rates and targets is commonly known as target costing, design to cost, or design to price. In the target costing approach,

"Marketing managers first estimate the performance characteristics and market price requirements in order to achieve a desired market share for a proposed product. A standard profit margin is then subtracted from the projected selling price to arrive at the target cost for the product. The product development team must then, through its product and process design decisions, attempt to reach the

product's target cost." [Kaplan & Atkinson, 1989]

Learning and improvement targets are set by the market, and the producers must meet these targets in order to profitably compete. This approach is typical of Japanese manufacturers, and is also being used to some degree by U.S. automobile manufacturers.

A shipyard's rate of learning and improvement is not, and can not be tied only to past experience (as defined by past production volume and performance) if the shipyard wishes to remain or become competitive. To be competitive, a shipbuilder must improve from its present level of performance at a time-based rate dictated by the anticipated market. Requisite present and future levels of competence, and rates of learning and improvement are dictated by the most competent competitors in the market.

Another problem with the experience curve learning model is that while it accounts for some of the marginal improvement seen in modern competitive commercial organizations, it only recognizes unconscious learning. Unconscious learning is, as implied, learning that is accomplished unconsciously through experience, either through imitation, or more formally through reaction to reward and punishment. What the experience curve learning model ignores is conscious learning which relates to formal education and conscious problem solving. The recognition of the role of conscious learning is important because

"Conscious learning leads to a higher level of competence, in that it is additive and on-going . . . . In other words, conscious learning helps to develop learning potential, the potential to control one's own learning. By contrast, unconscious learning is repetitive imitating role models, or repeating behavior which is rewarded and avoiding that which is punished. There is no innovation or change in perspective (with unconscious learning) . . . ." [Swieringa & Wierdsma, 1992]

Following are a few key reasons why conscious learning is extremely important to gaining and retaining competence and competitiveness. First, conscious learning begins with learning about the experiences of others so those experiences do not have to be repeated. In this way individuals and organizations can start at a higher level of competence by avoiding having to learn from their own experience what others have already learned and documented, "reinventing the wheel." Second, as implied above, conscious learning results in greater perspective that leads to more open-mindedness toward new ideas. Finally, conscious learning includes the application of

structured problem solving methods, which, when applied by empowered, open-minded personnel facilitates creativity and breakthroughs beyond traditional individual and organizational paradigms, and results in innovation. One common conscious problem solving approach used for process improvement is the classic plan-do-check-act (PDCA) approach, sometimes called the Deming Cycle. In this approach, problem solving teams use brainstorming techniques and one or more of the seven basic quality tools (pareto analysis, process flow charts, check sheets, cause and effect diagrams, histograms, scatter diagrams, and control charts) to develop, implement, review and improve processes. [Chase & Aquilano, 1992]

## EXAMPLES OF LEARNING BEYOND THE EXPERIENCE CURVE

Toyota Motor Company [Mishina & Takeda, 1992]  
[Chase & Aquilano, 1992]

For several years after the Second World War, very few people in Japan could afford to own a car. Also, immediately following the war Japan's labor productivity was only about one eighth that of the U.S. Toyota was thus challenged with the task of becoming a productive and competitive automobile manufacturer without the benefits of experience, high skill levels, or large production volumes. The company's leaders spent a considerable amount of time studying (conscious learning) successful manufacturing and business methods, and then set about creating the innovative Toyota Reduction System (TPS). The system started with a vision of "better cars for more people." From this vision arose some fundamental principles for the operation of the company, which were

- meet diverse customer preferences,
- do everything with flawless quality,
- eliminate waste,
- deliver the product at a competitive price, and
- deliver the product with perfect timing.

Based on the company's conscious approach to learning and problem solving, and on its vision and principals, Toyota introduced the following innovations into its operations.

- $\bar{Z}$  Group Technology - grouping interim products by production requirements, and then organizing production systems to efficiently produce each interim product type.
- Focuses Factory Networks - defining smaller, more specialized factories.
- Just-In-Time production - producing only what is needed when it is needed.
- Kanban - controlling production based on downstream demand or "pull."

- Jidoka - making problems instantly self evident and correcting them immediately.
- Kaizen - proactively and continuously working to replace all product and process standards with better standards.

Had the company relied upon the experience curve model of learning, and had it believed that its future success was entirely dependent upon incrementally improving on its initial low levels of competence and production volume, the company would very probably not have survived. While never having been a volume leader, Toyota became, and still is today, one of the most innovative and competitive automobile companies in the world by utilizing a conscious learning and problem solving approach and using its acquired knowledge to continually push beyond contemporary paradigms.

Avondale Shipyards [Chirillo, 1988]

In the late 1970's Lockheed Shipbuilding had built the lead ship and two follow ships of the LSD-41 Class. When the next flight of ships was bid, Avondale won the contract with a bid of about \$166 million to build LSD-44, as compared to Lockheed's bid of approximately \$225 million. See Figure 2 below.

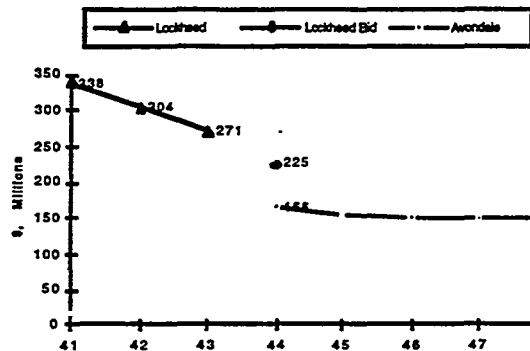


FIGURE 2. LSD-41 CLASS PRICES.

While recognizing that approximately one third of this price difference could be attributed to wage rate differences, Avondale still appeared to be significantly more competent and competitive while not having built even one of these products. How had they gained this level of competence without any experience in the production of the LSD-41 class ship? Their success has largely been attributed to proactive efforts at conscious education, rationalization, and innovation in the late 1970's and early 1980's. As a major part of this effort, they had established a technology transfer agreement with Ishikawajima-Harima Heavy Industries (IHI). With IHI's help, the yard had completely redefined its business and operations practices to support a product-oriented approach to ship production. The principles of

group *technology had* been applied to redefine and group interim products and redefine work processes into process lanes that supported the production of interim product families. This evolution is documented in great detail in the REAPS/NSRP literature. [Avondale Shipyards, Inc., 1982]

**Although** Lockheed shipbuilding had shown learning and improved performance during the production of the first three ships of the class (from a price of \$338 mil. on the lead ship to \$271 on the third ship), the company had either failed to adequately predict the level of competence that would be required by the market, or failed to successfully take the conscious and proactive actions necessary to remain competitive. Their failure in these areas ultimately resulted in their closure.

## A METHOD FOR MEASURING THE RATE OF LEARNING

An organization which has established an environment of continuous improvement has institutionalized processes of conscious learning. In order to be competitive in the commercial market, an organization must not only have established an environment of continuous improvement, but it must also be able to learn as fast as, or faster than, its competitors. Because the ability *to learn* at specific rates is important, it is also important to be able to measure the present rate of learning. Following is a brief discussion of Analog Devices, Inc.'s (ADI) implementation of a methodology for measuring internal rates of learning. [Kaplan, 1990]

Analog Devices produces integrated circuits and electronic devices and systems primarily for converting analog information into digital data. Their products are used in computers, aircraft sensors, scientific and medical instruments, and consumer electronics. In the mid-1980's the company began to see business stagnate in spite of their high quality work force and engineers, continual investment in the latest technology for design and production, and long-term business focus. The company's leaders concluded that they simply were not learning as a company as fast as their competitors. The company's chairman and president went as far as to argue that, "the rate at which individuals and organizations learn may become the only sustainable competitive advantage." [Stata, 1989] This learning should manifest itself in competitive rates of process improvements. The problem then was to determine what rates of process improvement were necessary to remain competitive, and to establish realistic process improvement targets over time based on present performance levels and on projections of the performance of competitors.

The company began to research learning models for manufacturing and business. In this research they identified that in competitive companies

process improvement occurred over *time* (not units produced) such that when some significant measure of process performance requiring improvement such as cost, duration, or defect rate, was plotted on semi-log paper versus time, it would form a decreasing straight line (unless a significant innovation was implemented during the period of measurement). This line would continue downward at a constant rate until some inherent limitations of the process would prevent more improvement, at which time a significant process innovation or breakthrough would be required for performance improvement to continue. See Figure 3.

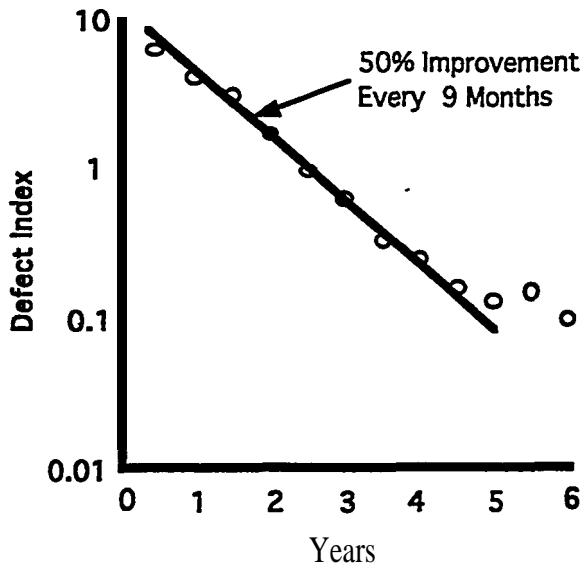


FIGURE 3. EXAMPLE HALF-LIFE GRAPH.

They studied many different types of processes by identifying and measuring a significant defect index for each process, such as error rate, cycle time, inventory level, absenteeism, accident rate, late delivery rate, parts-per-million defective, set-up time, and order lead time. They found that this learning model applied to most types of processes, and that rates of learning in competitive companies were steady over time even as production volume varied. The company then established how much time it would take to achieve a 50% reduction in the defect index of each process, and called this the process half-life measurement. They found that processes with high technical and organizational complexity had process half-lives significantly longer than processes with lower technical and/or organizational complexity, with organizational complexity being the most important factor. The company regularly produced performance reports that showed the half-life graphs and identified the half-life times for each internal process. Table I is a list of some of the company's half-life times for 1989. These numbers represent rates of learning and improvement expressed in half-life months, or the number of months required to reduce the identified process defect indices by half.

Process Defect Index	Half-Life (months)
Errors in purchase orders	2.3
Failure rate, dip soldering process	3.7
Vendor defect level, capacitors	5.7
Accounting miscodes	6.4
Defects per unit, line assembly	7.6
Scrap costs, total manufacturing	13.8
Manufacturing cycle time	16.9
Accident rate	21.5
Late deliveries to customer (+0,-2 weeks)	30.4
Product development cycle time	55.3

TABLE I. SOME 1989 ADI PROCESS HALF-LIVES.

By establishing its present process performance levels and improvement rates, and estimating those of its competitors, a company has some information that it can use to help determine whether it is learning fast enough to compete, and to use as a basis for establishing process performance and improvement targets.

#### OBSERVATIONS AND CONCLUSIONS

"The rate at which individuals and organizations learn may become the only sustainable competitive advantage." [Stata, 1989] The importance of this statement can not be underestimated in today's intensely competitive environment. However, because the experience curve model of learning has been presented for nearly a century as the only model of learning, as evidenced in this paper's first and second references [Erichsen, 1994] [Thurstone, 1919], many individuals and organizations have fundamental misunderstandings of factors affecting, and approaches to, individual and organizational learning.

It is in these difficult times for the U.S. ship building industry when innovation and breakthroughs are needed most. Unfortunately, during difficult times in U.S. companies in general, one of the first areas where cuts are made is in education and training programs because traditional managers characterize these programs as nonessential overhead rather than investment, and the financial accounting rules reinforce this view by requiring that these costs be expensed as they are incurred. Along these lines, some U.S. shipyards have been downsizing and, in some cases, eliminating their management training, continuing education, and tuition reimbursement programs. Also, many U.S. yards are no longer providing support for their representatives to participate in the NSRP SP-9 Education and Training Panel, and the senior shipyard representatives on the NSRP Executive Control Board have shown a significant lack of support for projects proposed both by SP-9 and SP-5, the Human Resource Innovations Panel, over the last few years. U.S. companies in general, and U.S. shipyards in particular, must begin to recognize that support of education and

training at all levels is an investment in their most important resource and in their future.

There are also political issues related to fundamental misunderstandings of how learning occurs and competence evolves. Many in domestic shipyard leadership and the U.S. government have, at least in the political arena, attributed foreign shipbuilding competitiveness to the experience they have gained supposedly building large numbers of standard commercial ships in series for many years. To quote from the Shipyard Council of America's (SCA) January 6, 1994 *Shipyard Chronicle*,

"For the (U.S.) yards that developed the capabilities to produce complex warships, the transition (to commercial production) will be harder. It is not as some pundits would have you believe simply a matter of making changes in the corporate culture. It is the case that overcoming the advantages of long-term series construction by our competitors makes the task of market entry very difficult."

Because of this belief, or position, some industry leaders and government officials have been lobbying for a federal subsidy for the development and production of standard series commercial ships in US shipyards. Quoting the same issue of *Shipyard Chronicle* referenced above,

"...there should be the development of a Series Transition Payment (STP) program which would help yards make the transition to commercial markets and offset the advantages of series construction that our competitors have enjoyed."

The perspective represented by these statements is fundamentally flawed in several ways. First,

only a very small portion of ocean-going ships that have been built in the past several years have been part of standard series production runs. Figure 4 below is a graph of some of the data presented by a representative of the Association of Western European Shipbuilders (AWES) at the Shipyard Industrial Game put on by the Center for Naval Analysis in December 1993. This data shows that 85% of the inquiries received by AWES shipyards in 1993 were for order quantities of three vessels or fewer, with over 70% of inquiries for ships in quantities of one or two. The AWES representative presented this data specifically to point out to U.S. shipbuilders who were present at the Shipyard Industrial Game that the "long-term series construction" market is extremely small, and it has been very small for many years. In fact, on average ship owners are looking for ships with many custom features, generally in quantities of one or two. Foreign shipbuilders who recognize this market truth have been, and are now, targeting these customers and meeting their demands.

Second, when these industry representatives attempt to apply the experience-based learning model to ships as the units of production, the implication is that the production of a ship is a traditional one-off construction project. This perspective fails to recognize that modern shipbuilding is a manufacturing process that is subdivided into the fabrication and assembly of many families of similar interim products using a group technology-based product work breakdown structure. Whatever experience-based learning and improvement that is being gained by competitive shipbuilders is being gained at the interim product level, not at the level of the final product. When viewed from a manufacturing perspective, what becomes important from the standpoint of gaining experience is repeating the manufacture and assembly of similar interim products, regardless of the type of ship to which any one particular interim product might happen to belong.

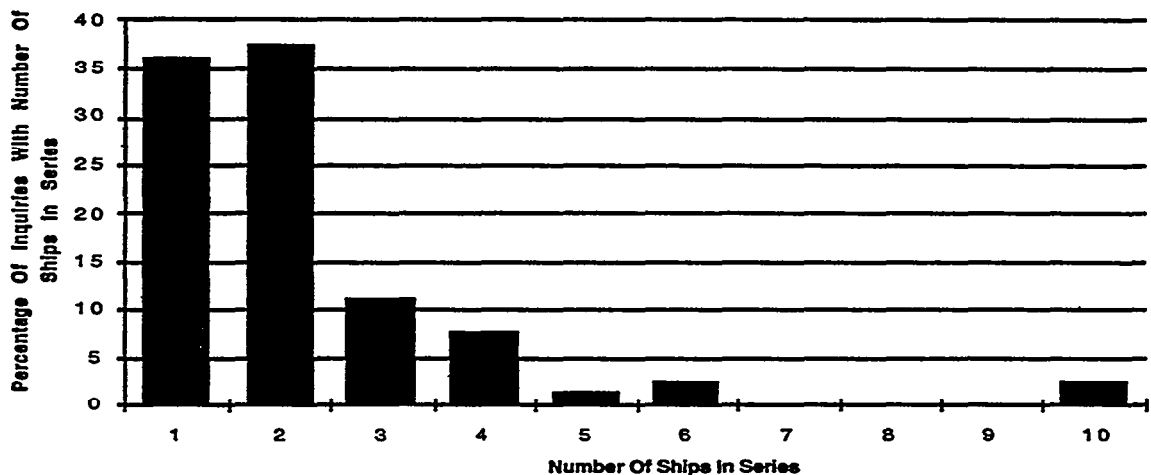


FIGURE 4. 1993 AWES % INQUIRIES BY PROPOSED NUMBER OF SHIPS IN SERIES.



The process of assembling a "flat block" is essentially the same whether that particular "flat block" is part of a container ship or part of a product carrier. If a shipyard has done an adequate job of defining and using a product-oriented design and production approach, standardizing its interim product type-s and production processes, significant commercial shipbuilding experience can be gained without the need for standard series ships.

Finally, as discussed throughout this paper, the views expressed by some shipyard representatives and the SCA relative to series production demonstrate the typical misunderstanding of the learning process: that leaning is based only on experience. This perspective ignores the more significant potential of conscious learning and problem solving. Only through conscious approaches to learning can organizations hope to break free of ongoing repetition and incremental improvement of past noncompetitive practices, and begin to learn and improve at competitive rates.

Competitive companies do not allow themselves to be limited by their past experiences. Ultimately, the shipyards that compete successfully in the commercial market will be those that have made, and continue to make, considerable conscious effort to learn the market, learn their competitors' and their own capabilities, and learn what the best competitors in other industries are doing to be successful. These yards will be consciously apply problem solving methods and their growing knowledge to create innovative solutions to their problems and improved ways of doing business. Those yards that fail in their attempt to enter the commercial market may be trying to ride the experience curve to competitiveness as their competitors pass them by.

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# **Concurrent Engineering: Application and Implementation for U.S. Shipbuilding**

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Textron Marine & Land Systems; U.S.A.

## **ABSTRACT**

*This* paper reports on a SP-8 Panel project to analyze the application of Concurrent Engineering (CE) in U.S. shipbuilding and to perform a pilot implementation of CE within a U.S. Shipyard. It describes 1) results of a Shipbuilding Concurrent Engineering Questionnaire survey 2) a summary of product development performance benchmark surveys conducted at several U.S. shipyards, 3) visit to several foreign shipyards as well as Boeing Commercial Aircraft Company, Lockheed Missiles and Space Company and the Concurrent Engineering Research Center to discuss implementation of CE; 4) requirements for successful CE implementation by U.S. shipbuilders, and 4) the status of the pilot CE implementation at Bath Iron Works Corporation.

## **INTRODUCTION**

Today the major challenges facing U.S. shipbuilders as they plan to enter the world commercial shipbuilding market are how to shorten delivery time, reduce ship prices, and improve the world's perception of U.S. shipbuilding quality.

This scenario is not unique to shipbuilding. Many U.S. industries face the same problem.

The first companies to look for a way to match world competition were in the automotive, commercial aerospace, machine tool and electronics industries. Defense oriented industries later jumped on the bandwagon with considerable assistance from the Defense Department through DARPA, the originator of the term Concurrent Engineering (CE). In the early 1990's Ingalls Shipbuilding utilized CE in the design and construction of the SA'AR 5 Frigate, Lindgren et. al., 1992, and Newport News Shipbuilding used CE on a number of development projects, Blake, et. al., 1993. Prior to that General Dynamics (GD) Electric Boat has been using elements of CE for submarine design from 1950 until today. Based on this experience, when GD embarked on their LNG program they successfully adopted a CE approach. However, at that time it was not specifically labeled as CE, Bergeson 1993.

In an effort to promote CE within the U.S. shipbuilding industry, the SP-8 (Industrial Engineering) Panel defined a project to involve a team of concurrent

engineering practitioners in working with a U.S. shipyard to implement concurrent engineering, document the implementation process and share the results at a marine industry workshop.

The objectives of the project were

1. To determine extent of Concurrent Engineering application in shipyards, the familiarity of shipyards with the use of CE and potential benefits from its application.
2. To show how Concurrent Engineering reduces time to design and manufacture a product while improving quality and reducing cost.
3. To produce a user's guide and primer for Concurrent Engineering application to U.S. shipbuilding industry as a first step to actual implementation.
4. To implement Concurrent Engineering on a specific shipyard design and construction program

The project has been broken down into two phases, an Application Study Phase and an Implementation Phase. Objectives 1 through 3 were accomplished in the Application Study Phase of the project including the development of a comprehensive User's Guide and Primer for publication through the National Shipbuilding Research Program (NSRP). Objective 4, the actual shipyard implementation, is presently being performed by Bath Iron Works Corporation (BIW), and is expected to complete during the first quarter of 1995. The implementation effort is one element of a larger MARITECH focused Development project involving the development of RoRo type commercial vehicle carriers commonly referred to as Pure Car Truck Carriers (PCTC).

This report defines Concurrent Engineering, examines how it can be used to improve and ensure a successful product development process, reviews the current status of CE application within U.S. and foreign shipbuilding industries, identifies the essential requirements for successful CE implementation and highlights current progress in the implementation of CE at Bath Iron Works Corporation.

## WHAT IS CONCURRENT ENGINEERING

Concurrent Engineering is a misnomer in that it has always covered more than “engineering.” At its outset it was the concurrent design of the product and its manufacturing processes. It has grown to include all product processes from the cradle to the grave.

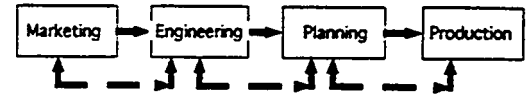
Like Just-In-Time, CE is a philosophy not a technology. It uses technology to achieve its goals.

The main objective of CE is to shorten time from order to delivery for a new product at lowest cost and highest quality. It does this by using a parallel rather than sequential process for the different functional parts of the product design. This is accomplished through the use of Cross-functional teams.

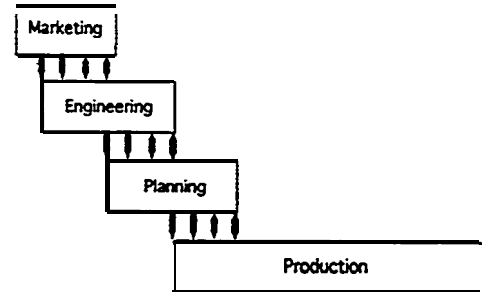
Figure 1 schematically shows the differences between the traditional sequential, overlap, parallel and the CE approaches.

The generally accepted definition of CE was prepared for the Institute of Defense Analysis (IDA) in 1986 (IDA Report, 1988), and is

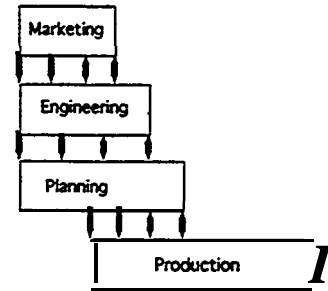
*Concurrent Engineering is a systematic approach to the integrated, concurrent design of problem and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule and user requirements.*



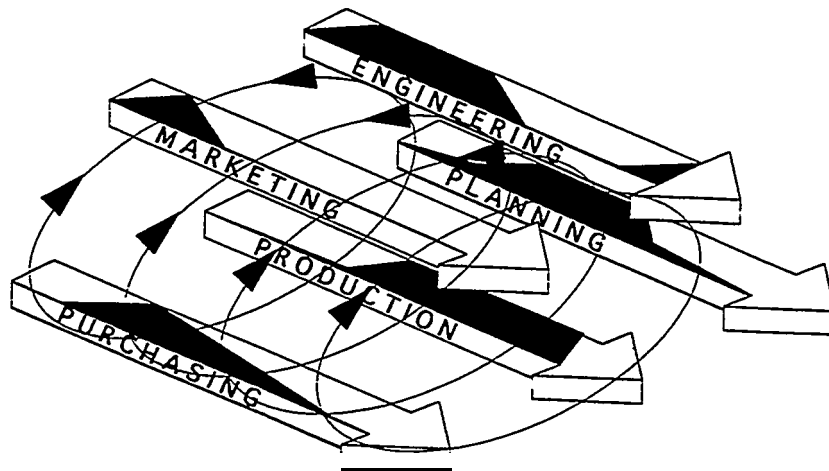
(a) - SEQUENTIAL



(b) - OVERLAPPING



(c) - PARALLEL



(c) - CONCURRENT (PARALLEL AND INTEGRATED) PRODUCT DEVELOPMENT

FIGURE 2 - COMPARISON OF PRODUCT DEVELOPMENT PROCESSES

A more recent definition from the Concurrent Engineering Research Center (CERC) (CERC, 1992) is:

***Concurrent Engineering is a systematic approach to the integrated development of a product and its related processes, that emphasizes responsiveness to customer expectations and embodies team values of cooperation, trust and sharing, in such a manner that decision making proceeds with large intervals of parallel working by all its life cycle perspectives, synchronized by comparatively brief exchanges to produce consensus.***

In both definitions two words are used that need to be redefined for completeness and to avoid misunderstanding. They are

**DESIGN** - The *development of all product attributes through engineering, planning, ordering, manufacturing, testing, operation and disposing.*  
**PROCESS** - An *ordered series of steps performed for a given purpose.*

The most practical definitions of CE, quoted to the writer by Dr. Ralph Wood of CERC, are:

***All functions work as a team in parallel, plan early, validate often and maintain oversight of product life cycle decisions within their control.***

and

***Concurrent Engineering is systems engineering performed by cross functional teams.***

The IDA definition makes reference to involvement through disposal and the others make reference to life cycle. While this may be practical for some industries, it is not for shipbuilding. While it is true that designers avoid the use of certain materials, such as asbestos and HALON, which cannot be used due to certain life cycle problems, in general, the shipbuilder is only associated with a commercial ship until it has completed its warranty period. To make the definitions fit, commercial shipbuilders should consider delivery and completion of warranty period as their disposal. This does not mean that the shipbuilder should not attempt to take into consideration any and all life cycle information and requirements a shipowner is willing to share with the shipbuilder. It simply reflects a current fact of life. By including the shipowner on the CE team will help achieve this.

CE is customer, process and team focused. While "customer" obviously means the purchaser and user of the product, it also means the company internal users of the output from the different process involved in producing the product.

The CE approach is known by other names, such as Simultaneous Engineering, Concurrent Product Design and Integrated Product Development. Part of the reason for this is that implementers ran into cultural problems when attempting to get non-engineers involved in "engineering" or "design." It appears that the most acceptable name is Concurrent Product Development but it is the approach that is important not the name.

Ideally, CE involves all the product development participants, including the customer and the company's suppliers, in a team environment, at the start and throughout the design of the product and its processes.

CE is not new. The approach has been used by many companies worldwide for some time. Experience has shown, that, if applied properly, it will achieve its stated benefits.

Many companies that attempted to implement CE failed to accomplish it or to achieve any benefit from the attempt. In many of these cases the situation has been well researched and documented in the proceedings of conferences addressing CE. These can be read and used by other companies to help prevent the mistakes that were made by the other organizations. It is recorded in these reports that the most common reason for the failures was the inability of management to effectively manage the introduction of the required changes in their processes and their culture.

There are two basic approaches to CE namely team based and computer-based. The team based approach focuses on collocated cross-functional teams that bring their diverse specialized knowledge together at the start of a project. To be successful this approach involves significant training in team skills. While the team based approach is frequently adopted, it has many problems, such as lack of team skills, lack of experience in team management and the cost of maintaining the team.

The computer based approach attempts to provide all the tools required to accomplish the tasks in a CE environment. That is, to develop, capture, represent, integrate and coordinate the required knowledge and to permit instantaneous access to all users of the information. Real time access to shared information is a central concept of CE. It recognizes that a large number of non interfacing existing computer tools are used to develop a product design. The lack of integration of these tools is a significant problem for CE users. Consequently the interfacing of these stand alone tools is the major emphasis for the computer based approach.

Today both approaches appear to be merging into one as they both compliment each other, especially as more sophisticated computer tools are developed which

Recently other computer tools, such as Computer Aided Process Planning (CAPP), Artificial Intelligence (AI) and Expert Systems (ES) are being added to the list of tools that can enable the best implementation of CE. This will ensure that all important aspects of the product design will be given the connect consideration early in the product design process and that the lessons of the past are not lost, or worse still, the undesirable ones repeated.

With the contraction in defense spending many U.S. shipbuilders are planning to enter the commercial market as it is the only way they can survive. The competition is already able to develop new products in shorter time to market, at considerably less cost and at globally accepted quality levels. To successfully enter the global commercial shipbuilding market U.S. shipbuilders must change their approach to enable them to produce a high quality, competitive cost ship in the shortest possible time. Cost reductions of 30 to 50% and similar design and build cycle reductions are necessary. Obviously, to accomplish this the shipbuilders must have a backlog of ships to build or it does not make sense. To buildup the skilled manpower for such short duration shipbuilding for one or even two ships would not support long term full employment. First ship deliveries of 18 months require at least one ship per year on a continuing basis.

Realizing that this is a “chicken and egg” situation, that is, the U.S. shipbuilders cannot win international commercial ship contracts until their cost and delivery time are both reduced and this cannot occur until they have sufficient ships in their order book, it is still suggested that U.S. shipbuilders must take the initiative in implementing the necessary changes.

While the introduction of improved shipbuilding techniques, such as zone design and construction, and improved shipbuilding process through the utilization of the Build Strategy approach, have resulted in a narrowing of the gap between U.S. and best foreign shipbuilders, they are not enough. Something needs to be done to propel the U.S. shipyards to at least the level of the best competition, and then to find and sustain a competitive advantage over them.

CE recognizes that most of the cost of a product is established early in the design stage and that the cost to make changes increases geometrically as the product progresses through the development cycle, as shown in Figure 2.

Reported benefits that have actually been attained are shown in Table I. If these improvements could be achieved by U.S. shipbuilders, they would be well on their way to successfully capturing a meaningful share of world shipbuilding orders. The reported benefits of CE (that is, lower cost higher quality and shorter design and build cycles) would appear to be exactly what is required to help U.S. shipyards attain the ability to enter the highly competitive global commercial shipbuilding market.

DEVELOPMENT TIME	30-70%	REDUCTION
ENGINEERING CHANGES	65-90%	REDUCTION
TIME TO MARKET	20-90 %	REDUCTION
OVERALL QUALITY	200-600%	IMPROVEMENT
PRODUCTIVITY	20-110%	IMPROVEMENT
DOLLAR SALES	5-50%	IMPROVEMENT
RETURN ON ASSETS	20-120%	IMPROVEMENT

Source Institute for Defense Analysis



23-4

of the down stream constraints as early in the process as possible. This forces all participants to become more aware of the wider aspects of the total process and to give these aspects consideration in their areas of specialization. The potential benefits are obvious.

## MAJOR CHALLENGES

CE offers a special challenge to management in that it demands significant change in the way products are developed. Management's previous experience probably has not prepared them for such a change. If a shipyard has never used CE, there will be no experience within the shipyard. Yet if the shipyard does not start to use CE, it will not gain the experience.

CE is not only the concern of engineers. CE involves fundamental changes in how a company is managed. CE will impact every aspect of a company's operation. Therefore management must take an active part in planning the CE implementation. To take part in this planning, management must first educate itself and then educate its employees.

While the use of CE is increasing, the traditional sequential "pass it over the wall" approach to product design is still the most common method. Even when the benefits that other companies achieved from CE are known, many companies or groups within companies resist its implementation. This resistance can range from the natural resistance to change, inherent in most people, to deliberate action by an individual or group based on belief that the change would be detrimental for **them**. Management must recognize this and take preventative steps.

Experience of successful CE users is that the required changes are transformational, that is fundamental, organization wrenching and far reaching. Because of this, some attempts to implement CE have failed as management and employees have not accepted the necessary changes. Some others have chosen after conducting extensive exploratory studies not to even try to implement CE because the extent of the required change was unacceptable to their management.

There is considerable knowledge, experience and research on the subject of managing successful change in a business setting (Tichy, 1983 & Adizes, 1992). While its application will not guarantee successful incorporation of change, an understanding of this information will certainly help to increase its probability of success.

The biggest challenge is being able to successfully bring about the foundation wrenching changes that will be necessary in organization structure and management.

After the CE implementation has started, management must clearly show continuing support for the implementation by providing whatever resources are necessary to make it work. When this level of support by management is seen by the employees, they begin to believe that it is the new way and want to be part of it

The next two biggest challenges are the need to change the company's culture and way of operating. They are both required and reinforce each other. The most visible is the operational change (the way things are done). However, what you see may not be real. False support by managers and employees is an insidious disease that will cause the implementation to fail. While it may seem that a company's culture would be visible, this is not so. There are many underlying and conflicting influences that result in a company's "visible" culture. It takes considerable skill and effort to analyze a shipyard's culture, but this is an essential part of the management of change. The change in the way of operating must be correctly aligned with the stated objectives of the change and must be completely supported by all levels of management. Management is the driver. If the actions of management do not reinforce the stated way things are to be done, then no matter how enthusiastic they are, employees will find it difficult to successfully implement the changes. The change in culture must match the desired mode of operating.

Typical changes require moving from

- department focus to customer focus,
- directed individual or group to coached **team**,
- individual interests to team interests,
- autocratic management to leadership with empowered followers, and
- dictated decisions to consensus decisions.

Many will recognize that most of these changes are required by any company moving from traditional management practice to Total Quality Management (TQM).

## PERFORMANCE OF THE PROJECT

The following Technical Approach was used to accomplish the project objectives

- a) Performed a mail survey of a number of U.S. shipyards to determine their familiarity/use of concurrent engineering.
- b) Visited 6 U.S. and 3 Japanese shipyards to obtain detailed input on their use and interest in implementing concurrent engineering and to determine how Japanese shipbuilders achieve short building times.
- c) Conducted technical research into U.S. aerospace companies noted for their application of concurrent engineering. Also used facilities and experience of the

Concurrent Engineering' Research Center (CERC) and the Center for Entrepreneurial Studies and Development (CESD) at West Virginia University.

d) Prepared a concurrent engineering primer covering its purpose, benefits and requirements. Included lessons learned in its use by other industries, as well as determined the suitability of concurrent engineering to the shipbuilding process, and whether it could assist in bringing about the desired reduced building time and cost.

e) Prepared a users guide for the application of CE in U.S. shipyards.

f) Prepared a Final Report.

## QUESTIONNAIRE

A questionnaire was prepared for distribution to U.S. and Canadian shipbuilders. Its purpose was to determine current understanding and use of Concurrent Engineering.

The questionnaire was sent to 29 individuals in 21 private and Navy shipyards. Where a shipyard had a representative on a Ship Production Panel, the questionnaire was sent to the Panel member with the request to get questionnaires to the right people and to encourage participation.

Even with the small number of questions, special mailings, and providing for stamped return, responses were received from only 6 shipyards. Five of the shipyards that responded to the questionnaires were willing to meet with the project team. Also the team met with BIW.

Four of the shipyards reported that they had used CE and that it resulted in improved performance. Three shipyards reported that they had achieved reductions in manhours, errors and rework and design build cycle times. However, only two shipyards said they were still using CE for ongoing projects. No reasons were given as to why the others were not using CE.

## U.S. SHIPYARD VISITS

The project team visited BIW, Avondale Industries Shipyard, St. John Shipbuilding, Peterson Builders, NASSCO and Ingalls Shipbuilding. Each visit lasted a whole day. A proposed agenda was sent to each shipyard prior to the meetings. The project team first met with the shipyard meeting coordinator and discussed the agenda and answered any questions about the visit. Then the team was given a brief tour of the shipyard. Next small group meetings were held with the different shipyard departments such as Marketing, Engineering, Planning, Purchasing and Production. The objective of these meetings was to give the team the opportunity to evaluate the shipyard's concurrent engineering involvement and to help select topics to be

covered in the formal presentation on concurrent engineering. At the start of the formal discussions the team presented background information on the project such as goal, objectives and approach. The formal presentation was based on material developed by ICD and each attendee was given a presentation workbook. Since the shipyard visits, Mr. Huthwaite has written a book (13) which covers everything presented at the CE overview, and more.

Almost every shipyard asked for examples of CE metrics. Although a few were briefly discussed, there was not enough time to clearly describe or fully document them. This has been partially done in B. Huthwaite's book (Huthwaite, 1994) and in the CE **PRIMER**. A very detailed approach to selecting suitable metrics for CE is presented in the CERC Report, **PROCESS ISSUES IN IMPLEMENTING CE (CERC, 1993)**.

After the formal presentation on concurrent engineering, a benchmarking tool was described. The shipyard attendees were then split into multi-disciplined groups of three to five people and benchmarked their shipyard considering 20 characteristics with 1 representing a low CE involvement to 10 representing complete use of CE. They first did this individually and then obtained consensus in the groups.

The team scores range from a low of 2.35 to a high of 6.25 with an average of 3.7. The shipyard averages range from a low of 2.59 to a high of 6.0 with an average of 4.0. The team also scored the shipyards based on the information gleaned from the morning face to face meetings and feedback during the formal CE presentation. In general there was good agreement between the team's scores with the lower scoring shipyards and low agreement with the higher scoring shipyards. While it is encouraging that *one* shipyard benchmarked itself on the average as a 6, and another shipyard had one team that benchmarked itself as a 6.25, the team did not see any practices or processes that would justify these high scores.

The general industry experience has two levels, one for designers from 3 to 4 and one for managers from 5 to 6. The majority of the shipyard results are similar to the designer range, but this is not a good match as most of the shipyard participants were managers. This means that the shipyards are further behind U.S. industry in their readiness for CE. However, the scores for industry in general are not very high and reflect the fact that the number of companies using CE is still small compared to the total number of companies!

The group were then asked to write down three questions on concurrent engineering and at least one question from each group was answered as a way to develop further discussion. Most of the questions related to teams. All the questions will be used as subjects to be covered in the development of the **CE USERS GUIDE FOR SHIPBUILDERS**.

Four of the shipyards that reported they used CE actually only used some of the CE approach, namely early involvement of production in the design process and parallel processing. Customer focus and use of multi functional teams were not clearly demonstrated. Also the "design review mindset" still exists in even these shipyards, and many "people" problems still have to be resolved. There are many functional managers who will not agree to the changes that CE requires, especially the elimination of internal politics and power-plays, and the building of trust and effective teamwork between all participants.

Most of the shipyards had used a parallel development approach for some time. The ongoing thrust was to involve the downstream participants in the total product development cycle as early as possible.

All of the shipyards reported that their biggest problems were getting the right people at the right time and for the time required. Production people were usually too busy with today's problems to spend time to develop work that they would not see in the yard for a year or more. Also, different people were sent to participate based on commit availability rather than on value. Another problem with those that had applied some of the CE/teaming approaches is that everything worked well as long as there were no crises. As soon as problems or conflict arose the people tended to move back into their old methods and alliances. The solution to these problems is management direction, communication and reinforcement of CE principles, and education and training of everyone involved, from the top down.

## FOREIGN SHIPYARD VISITS

Mr. Tom Lamb visited three Japanese shipbuilding company design offices and /or shipyards at the end of May and early June 1994. The companies were Ishikawajima Harima Heavy Industries (IHI) design office in Tokyo, Mitsubishi Heavy Industries shipyard in Nagasaki and Sumitomo Heavy Industries shipyard in Oppama.

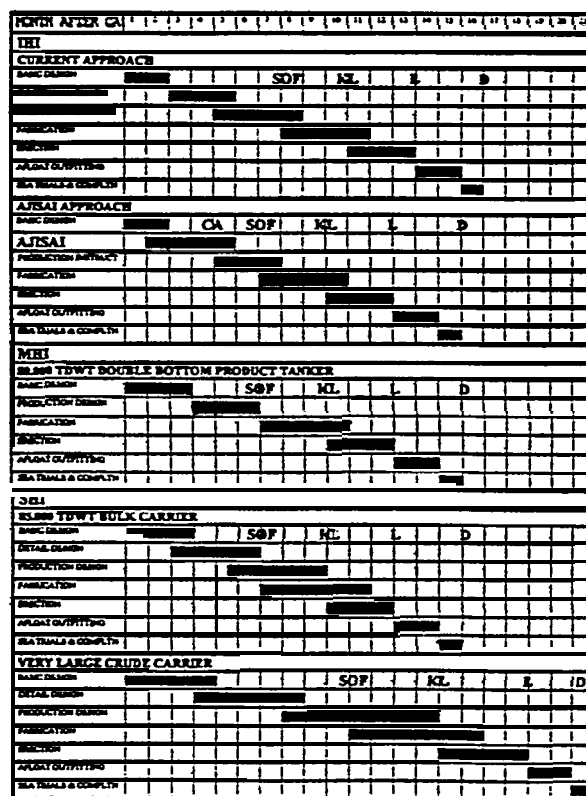
All shipyards were familiar with the term Concurrent Engineering and its meaning, mainly through reading English language books. However, none of the shipyards currently use much of the CE approach, nor do they utilize cross-functional teams, and yet they achieve some of the shortest design and build schedule times in the world. How do they do this

The short schedule duration's for time on the berth or in the dock, which range from 4 to 6 months, for commercial ships, are obviously dependent on erection crane capacity, space to construct large erection blocks, and the maximum use of advanced outfitting. The ability to start erecting a ship in the dock beside another ship already under construction, is also a big factor. That this is the case can be seen when it is considered that some single berth or single dock

Japanese shipyards can complete 5 to 6 ships in a year, and with 4 month erection times this means that there must be berth or dock time overlapping.

Surprisingly, the Japanese take a longer time after sea trials to deliver the ship than do some European shipyards. This may be because the Japanese choose to wait until after sea trials to completely clean the ship and perform all painting touch up, whereas the Europeans have the ship in the final delivery condition prior to sea trials.

All of the shipyard design groups are functionally organized, although some changes are underway. There appears to be little experimentation with cross functional teams or other "innovative structures to improve job satisfaction and empower the employees. However, it may simply be because they see no need or benefit from these options. The current close relationship between departments, teamwork and supporting (non-conflict) approach to their work appears to eliminate the need for cross functional teams. While some of the organizational options could be beneficial to both worker and employer this matter is not considered the best target of opportunity at this time.



**FIGURE 3 - TYPICAL JAPANESE DESIGN AND BUILD SCHEDULES**

It should be noted that, even in Japan, the design and build cycle time for naval ships ranges from 3 to 4 years. This is because it is based on government



funding schedules rather than what is the most efficient design and build time for the shipbuilder. Obviously, the government funding schedule has been established over many years and apparently gives a satisfactory outcome to the Japanese Navy.

Japanese shipyards involved in both naval and commercial shipbuilding do not mix in the same shipyard naval ships with the large tankers, bulk carriers and container ships. However, at the shipyards where the naval ships are built they also build high work content smaller ships such as ferries car carriers, small product tankers and handy size bulk carriers and LNG ships. This seems to be as much to provide a continuous manning level as it is related to any similarity in the needs for naval and the other types of ships. In the case of dual purpose shipyards, even the Japanese have the same problems that have been identified for U.S. shipyards planning to do commercial work while continuing their naval work. That is, how to effectively handle the different requirements for documentation worker skill levels and quality control.

All three of the companies visited are widely diversified in the international "heavy industry" market. While shipbuilding used to be the major part of their business, it is now only a small part. of diversification are bridge building, land power plants, desalination plants machine tools and aerospace. Another interesting point is that none of them are shipowners like many of the successful Scandinavian shipbuilding groups. However, they do have contact with groups of shipowners through their banks, trading houses and intercompany directorships.

Figure 3 is a summary of typical design and build schedules for the companies visited.

#### VISIT TO CERC AND CESD

Mr. Tom Lamb visited both the Concurrent Engineering Research Center (CERC) and the Center for Entrepreneurial Studies & Development (CESD) at Morgantown West Virginia on May 2 and 3, 1994. CERC has been developing CE tools and assisting companies to implement CE since 1989. CESD has been helping government and private companies to implement Total Quality Management and effective teams Since 1981.

In the morning of the first day, CERC showed a video and gave a general presentation on their formation, achievements, current activities and future plans. A demonstration of the CERC groupware to facilitate Virtual Collocation of CE teams was also given. The system involves video, audio, on line shared information, and the tools to permit many users to interface in real time.

Since 1993 CERC has decided to concentrate on developing computer tools/systems to enable CE. They no longer provide any training or on site CE assistance. Fortunately, this has been taken over by CESD who

will perform CE Readiness Assessments, Team Training and CE Implementation support.

CESD is currently involved in a number of implementation and team launch projects for both private and government groups. CESD could certainly help shipbuilders to assess their current readiness for CE and to perform a pilot implementation.

#### VISITS TO BOEING AND LOCKHEED

A visit to Boeing Commercial Aircraft Company was arranged in conjunction with an SP-4 panel meeting in Seattle on October 6, 1993. All members of the panel were invited to visit the Everett facility in the afternoon for the regular plant tour. In addition, a **special** presentation was given by the Boeing Publicity Department on the application of Concurrent Engineering and the use of 3D digital product model for the new 777 aircraft. The formal presentation described the need that forced Boeing into an improved approach and covered the highlights and achievements. Because of the approach, the 777 was Boeing's first aircraft that was built without the use of full scale mock ups. Also, it was anticipated that the approach would eliminate the months of system testing and rewiring that they traditionally had to perform after the prototype aircraft was turned over to the test group.

In the morning the team met with Mr. Ted Scoville the Boeing Concurrent product Development Manager who had the responsibility to overview the Concurrent Product Development (CPD) activities and to make it work. Mr. Scoville reported that Boeing had achieved significant benefit from the implementation of (2PD) but that people problems had prevented it from achieving its full potential.

He offered the following lessons learned

- Computers and 3D product modeling facilitated change required for CPD.
- Biggest implementation challenge was peoples resistance to change.
- Success of teams will depend on \_management control or lack thereof.
- Cannot apply CPD partially to a project. Must be all or nothing.
- Figure out a way to work within line organization without creating a new line organization for each product.
- Guard against non-design participants getting too involved in design.
- Middle management see CPD leading to job loss and breakdown in authority. Because of this teams are resisted by traditional middle managers.

- Organization must be made to fit the process.
- Top management must clearly state who the team members are working for and make sure the functional managers accept their new role.
- Teams must work hard at being a team otherwise they will drift back to traditional process.

The team also met with Don Norling, the Integrated Product Development Leader for the Missiles Systems Division (MSD) of Lockheed Missiles and Space Company on March 1, 1994.. MSD started using Integrated Product Development (IPD) in the 1980's. IPD has been applied on a number of programs with resulting benefits in quality, cost and schedule. Success is directly attributable to the fact that the second most senior executive in the company was the sponsor of the activity.

In late 1990 MSD established a team from different parts of the company to look at their development needs. Computer tool development was being developed by the Space Division and the MSD concentrated on the people side culture, teams, etc. The team, consisting of 3 full time and 12 part time members to develop and facilitate IPD in MSD. The team arranged for workshops from Bart Huthwaite covering CE and his Strategic Design approach. They prepared extensive promotional material including Users Manuals, and educational materials. MSD has a very impressive IPD Training/Conference room in which most of its material is on display. MSD are no longer in an IPD selling mode. IPD is accepted throughout the division and the challenge is now to keep up with demand for service and to ensure that programs and teams do not start without necessary training and preparation.

Mr. Norling offered the following lessons learned

- Many people believe they are already practicing IPD, but they are not
- Not aware of any company that has completely made IPD their way of business.
- Hardest group to bring onboard is engineering as they perceive a loss of status. Others are on the team as co-partners.
- Very difficult for others (production) to change from design reviewers to participants.
- Must get agreement in writing up front on the conflicting roles of Project Management Functional Management and Product Development Teams.

- Make IPD success part of performance appraisal.

Make sure teams know the difference between empowerment and autonomy.

- Use team contracts, charters and memorandum of understanding to facilitate communication and collaboration.
- Take time to train the teams and give them time to plan their activities.
- Have an IPD champion.

## IS YOUR SHIPYARD READY?

Once it is determined that CE is a suitable approach for a company to help it improve its operations, it is essential to see if the company is ready for CE. That is, is the company culture, practices and technology suitable for the transforming changes that are required?

Fortunately, others involved in the development of CE have recognized this need and have prepared various approaches to help companies answer this question. One such approach is the **PROCESS AND TECHNOLOGY READINESS AND ASSESSMENT FOR IMPLEMENTING CONCURRENT ENGINEERING** developed by CERC (CERC, 1992& 1993). This approach is based on the obvious premise that you need to know where you are before you can successfully set off in a specific direction and get to a desired destination. It uses the CE critical elements and process maturity stages, as well as the enabling technologies and their application level to map on a spider diagram a company's current CE readiness, such as shown in Figure 4.

Another assessment tool which does provide a measure of where you are and where you want to be as well as providing a "road map" of how to get there was presented in the book **CE CONCURRENT ENGINEERING: THE PRODUCT DEVELOPMENT ENVIRONMENT FOR THE 1990'S** (Carter, 1992).

By following the process described in the report a company can determine if it is "ready" to implement CE. The process will also indicate where any changes must be made before implementation should be attempted. Unfortunately, no guidance is given as to what would be an acceptable readiness level to assure successful implementation.

Although an assessment may seem like a very involved process, it is not and performing the assessments can prevent wrong decisions and later time delay and costly revisions to the implementation process.

## TEAMS

The use of teams in the workplace is not new. It probably goes all the way back to the earliest application of a number of people to a specific task.

Many books and articles have been written on teams. The intent herein is not to even try to discuss the many specific aspects of teams, but rather, to concentrate on their application to CE.

Teams generally form when it takes more than one person to accomplish a task. The use of teams is usually beneficial. Successful teams use the synergy of their

members to accomplish more and better things than a group of individuals not working well together.

A major characteristic of CE is the use of cross-functional teams, integrating the concurrent development of product and process design. In fact there is no CE if there are no cross-functional teams. Unfortunately, this is the most difficult part of CE. However, if the use of cross-functional teams can be successfully developed, the other requirements generally fall into place.

It is important to differentiate between teamwork and teams.

Teamwork occurs when individuals in a group or organization behave in a cooperative manner with all other individuals for the benefit of the group or

organization as a whole. Teamwork does not require teams.

Teams are groups of people established to accomplish a specific purpose.

*A team is a group that visibly shares a common purpose, and recognizes it needs the efforts of every one of its members to achieve this.*

There are many types of teams, such as:

task team,  
tiger team,  
cross-functional team, and  
Self-directed team

There are some implementers of CE that insist that collocation of the cross-functional teams is essential for successful use of CE. Then there are others who claim that the attempt to collocate team members led to the failure of their CE implementation due to lack of functional manager support and team members lack of

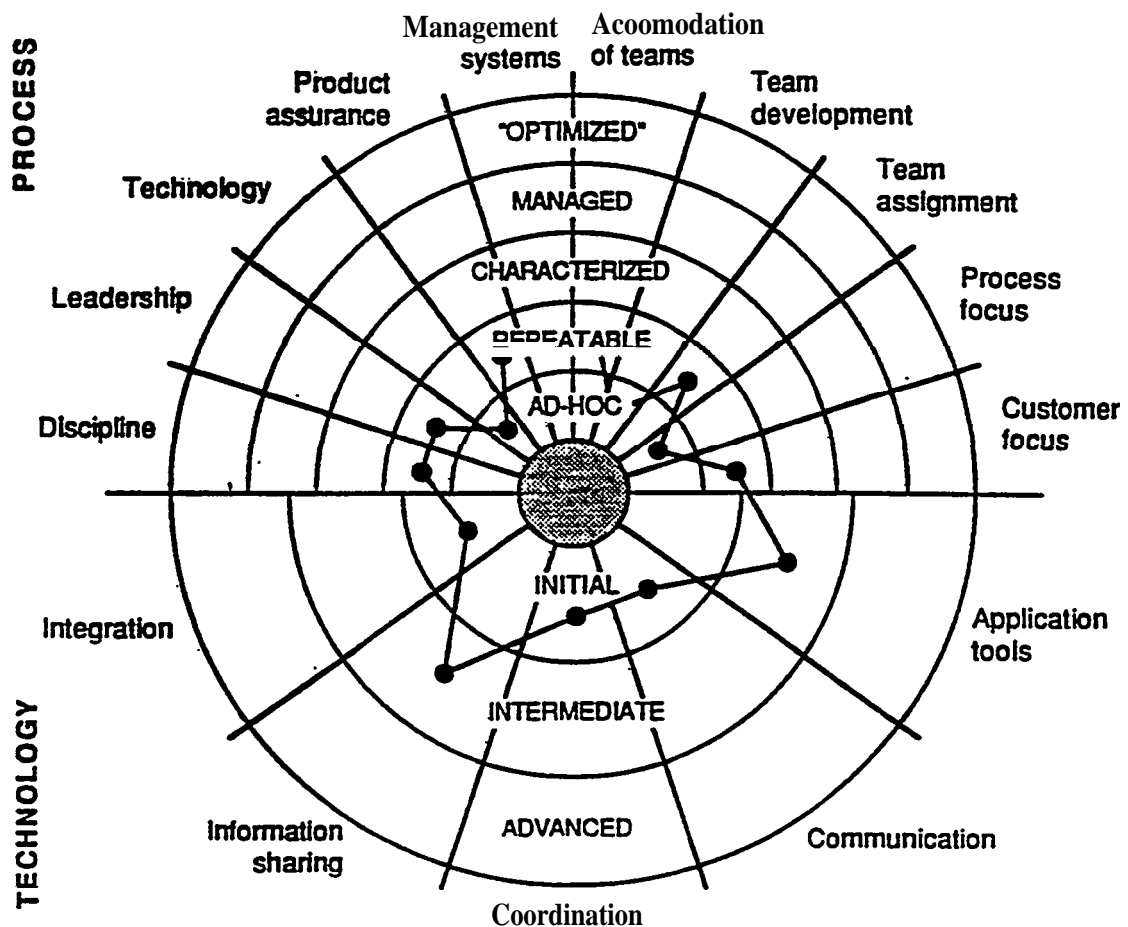


FIGURE 4 - CE READINESS ASSESSMENT DIAGRAM

functional belonging. What should be done? Probably, all the members of a CE pilot project team should be collocated. As CE is applied to other projects the team core members should be collocated. As CE becomes established in a shipyard and the use of computer tools is increase a move to virtually collocated teams can be made.

The CE process requires. real time interactive, ” integrated, and unconstrained input from many traditional functional specialists from the start to the fish of the product design. The most effective way to achieve this is to group the functional specialists into a team whose purpose is to accomplish a given assignment Such a group is a cross-functional team. Its members are generally of similar level in the organization’s hierarchy.

It is essential that a team be given training in how to operate as a team. Otherwise it will spend most of its time trying to find this out and probably will never reach it. So many times’ people are simply thrown together into a group, and told that **they are a team**, without being given any team training. This is obviously the wrong way to implement teams and could jeopardize the future of whatever propose they were formed

Training should be given on team skills such as communication emphasizing listening skills, group

decision making, conflict resolution as well as specific CE skills. In addition, the team members should be given clear direction on how the team fits into the existing organization structure and whether changes are planned.

## IMPLEMENTATION

Having determined that CE is the right way to improve the company’s performance and that the company is ready, the next step is to implement CE. Once the readiness status of the organization is known, this information can be applied to determine what strategic (process oriented) and tactical (tool oriented) decisions need to be made to implement CE.

As stated above, the implementation of CE by a shipyard will involve fundamental changes. The most obvious change is the way the product development is performed. Well established “comfortable” approaches must be replaced by new approaches. Other, not so obvious, changes are also required. me shipyard’s existing culture, technology, organization and operational methods will all need to be realigned to support the new product development processes.

Of these, the culture, will be the most difficult to change. Complete trust openness, cooperation and

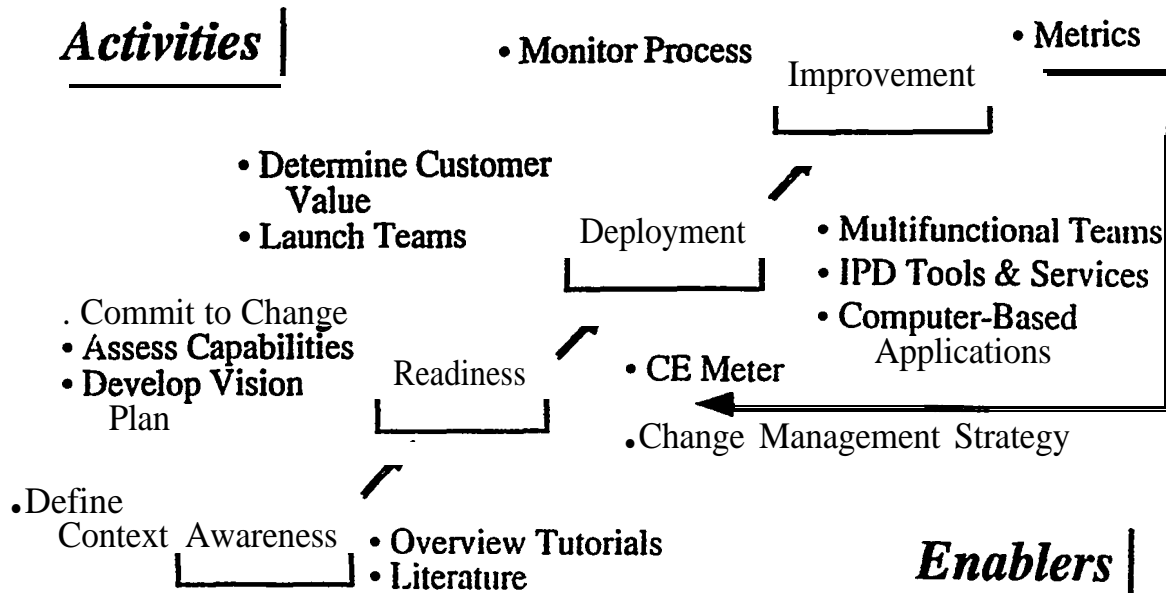


FIGURE 5 - CE IMPLEMENTATION

collaboration cannot be imposed on a shipyard. They must be earned and that takes effort and time. This is why an assessment of current status of these aspects is so important and must be done before any attempt to implement CE is undertaken.

The big question is what should be tackled first? Should the **cultural changes** be made before the product design process changes or vice versa? If a lot of time was available changing the culture first maybe the best way. However, time is usually not available and the best approach appears to be the concurrent development of both the new culture and product design processes.

Management and employees must believe that implementing CE will improve the company's performance. Because of this, most companies introduce CE as a small pilot project that can quickly show the benefits. A shipyard should carefully select the project and CE implementation team to give the best chance of success. Then they can build on this success in stages by using members of the successful pilot project team to be "champions" for new project teams.

Seeing is believing, so the best approach is to get people involved in actual projects. However, the team members must be given the training necessary to help them function correctly in an actual CE project. Without the required training, the outcome will be uncertain.

As CE is not a single event but a continuous journey, the final part of the implementation process is continuous **IMPROVEMENT** of the product and the design process by monitoring and measuring the product design process. Figure 5 shows this approach with the **ACTIVITIES** and **ENABLERS** at each stage, as well as the feed back loop for continuous improvement.

### Barriers to Implementation

CE is a non-traditional approach to the product development process, and while many of its concepts are logical, its implementation may be perceived by many as radical change and thus generate significant barriers to its acceptance and support. There are both organizational and technical barriers. Organizational barriers are probably the most difficult to remove as they can involve deep seated beliefs and values, management style, structure and policies. Technical barriers are the result of inadequate enabling technologies and knowledge to facilitate the implementation of CE, such as accessibility of all users to the product model and instantaneous sharing of information. Organizational and technical barriers are interrelated and this adds to the complexity.

As with any plan to implement change, it is essential to know where the barriers to the intended change are, so that they can be lowered or removed. In spite of the reported benefits of CE, it has met great resistance in many places. The reasons for this

resistance are many and complex. Some of them have been identified by previous CE implementers and include

- Lack of well defined measurable and repeatable approaches to the effective implementation of CE.
- Unwillingness to undertake the significant changes to status quo required by CE.
- Don't know how to fit CE approach into existing organization.
- Management and workers lack of experience and knowledge of how to operate as teams.
- Team member lack of customer interface experience.
- Perceived threat to functional managers position and authority
- Lack of CE knowledge and experience.
- Lack of top management support.
- Unsuitable organization culture.
- Inadequate time allocated by top management to support CE.
- Accounting systems not able to support CE approach.
- Individual performance appraisal and reward systems.

To overcome these barriers a plan must be established and each one taken care of. CESD have used the Quality Function Deployment (QFD) process to develop this type of plan for a number of clients. However, it is not easy, nor certain of success. As Machiavelli stated, many years ago, in "**THE PRINCE**," implementing change is very difficult due to lack of support from people, and never is certain of success.

### Common Failure Modes

A excellent discussion of this aspect of CE implementation was presented by Parsaei and Sullivan, 1993. Figure 6 is taken from that reference. It shows the many modes of failure and their relationship to the phases of implementation as well as the influence of management and employees at each mode. It should be noted that the items listed were all lacking and thus led to failure of the implementations. The chart can be used as a failure avoidance plan for implementation teams by ensuring that each mode is correctly and adequately considered. Regular review and comparison to the teams own experience may enable them to avoid the usual problems.

## Lessons Learned

There have been many implementations of CE throughout the world. There have been failures as well as successes. It is normal to report on the successes and not the failures and this has been done at the many conferences and in publications. However, even the successful implementations were not problem free. From these reports it is possible to develop a list of lessons learned. First the elements that appear to enable success and then the things to avoid will be listed.

### Lessons for Success

- The reason or need for the change to CE should be shared with all participants.
- Assure that all participants have a

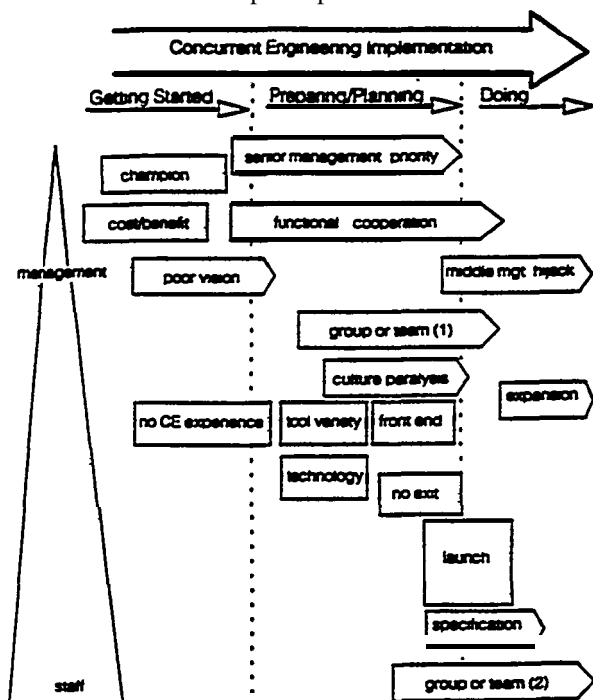


FIGURE 6- CE COMMON FAILURE MODES

common understanding and definition of CE.

- Gain personal experience by performing pilot projects.
- Carefully select pilot project. It should be real, visible and achievable in a short time.
- Build on pilot project success by forming more pilot project teams after each successful pilot project completion.

- Use enthusiastic successful team members to assist faltering teams and convert doubters.
- Select best personnel for Pilot Project Team(s).
- Institutionalize successful CE implementation. Ensure CE becomes part of the shipyard culture.
- Sell the approach from the top down - The vision has to come from the top. However, implementation must be from both the top and bottom. Commitment must be shared from the top to the bottom.
- Use a CE Steering Committee for top/middle managers who can become CE champions.
- Use a member of the Steering committee as the sponsor for product teams.
- Production role must be clearly defined up front to prevent them from simply extending their customary "design review" role.
- Train cross-functional teams not functional groups.
- Training of teams in team skills must be completed before team starts on the actual product design process.
- The organization structure must be changed to fit and support the CE process.
- Let the new CE team(s) visit established teams to see the results and how others apply CE.
- Functional managers must be trained for their new role.
- Functional managers should be involved in defining their new role.
- Reward system must encourage team success and not individual performance.
- Use frequent top management reviews to keep them involved in process and share ownership of decisions.
- Both customer and major suppliers must be involved as full team members.
- Develop and get management and team agreement on metrics that measure product and process quality and performance before the product design commences.
- Team must develop its operating process before starting product design process.

- Team goals and operating boundaries must be clear.
- Teams must continually measure how they are performing as a team.
- Use a comprehensive CE Implementation Plan for each pilot project until CE is institutionalized in the shipyard.
- Establish shipyard wide guiding principles and values.

#### Things to Avoid

- Partial implementation of CE. Must select a slice through the complete organization involving as many of the departments as possible for the team rather than just a few “important” departments.
- Changing tools and information without - - C h a n g e s .
- Management understating extent of change required to successfully implement CE.
- Management sending mixed signals about CE - saying one thing but doing another.
- Failure to remove/replace problem members in (CE teams).
- Mockery of delegated authority by management over-riding team decisions
- Functional management constraining cross-functional team members by insisting they be consulted before members make decisions.
- Ignoring the customer.
- Ignoring the suppliers.

#### Metrics

The need for metrics in implementing CE should be obvious. Without them improvement changes cannot be verified and the management of the CE process cannot be monitored and will be ineffective. All the reports on CE ‘lessons learned’ clearly state the essential need for appropriate metrics to be available up front and used in the CE implementation process. And yet very few reports, articles or books on CE give good examples of suitable metrics. They state that both the product quality and process effectiveness must be measured but they do not say how! Where examples of metrics are given they are “macro” measures and not specific enough for the performance of the CE processes to be completely assessed.

A metric consists of two or more measurements or single data points. For example, product design manhours is a measurement but the comparison of current product design manhours to previous product design manhours is a metric.

The lack of a commonly accepted CE process, lack of measurement standards or even norms and the multi-faceted interface complexity of CE, add to the above problems to make the development and use of CE metrics very difficult.

CE metrics must address the basic tenants of CE, namely,

- integrated product and process design
- concurrent product and process design
- meet customer requirements,
- use -cross-functional team, and
- consensus decision making

Metrics should be;

- Simple,
- easily obtained,
- objective - different people assign same value to the metric,
- valid-measure what is intended,
- robust - insensitive to small changes in product or process, and
- provide a basis for predictive process modeling.

Metrics can be “off-line” (pre/postprocess) or “on-line” (in process). On-line metrics are more useful as they provide an active control of the CE process. Obviously, they can be both qualitative or quantitative. CERC divided metrics into primary and secondary types. The primary metrics are the major areas of concern for CE, namely product quality, cost and cycle time. These measure the outcome of the product development process. The secondary metrics measure how well CE is applied or the effectiveness of the product development process.

Once the metrics are developed it is still necessary to decide how the information will be collected, the metrics computed and the results used. Also, for special metrics developed by a shipyard, the question of validation must be answered.

Notwithstanding these problems with metrics, it is better to have invalidated metrics than no metrics. As the metrics are applied over time they can be refined.

Useful measurements are

- customer satisfaction,

- product cost,
- time to market,
- product design manhours,
- product design time,
- process design manhours,
- process design times,
- number of engineering changes,
- duration of time changes,
- manufacturing manhours,
- manufacturing time,
- number of quality defects,
- product design manhours for rework
- process design manhours for rework,
- manufacturing manhours for rework,
- functional integration - number of functions involved in product design
- time to reach team consensus,
- number of meetings to reach consensus,
- team commitment and
- number of new products launch per year.

These measurements can all become metrics by comparing current value with past values. Other CE process metrics are ;

- concurrency index,
- common understanding ratio,
- team dispersion index
- requirements stability,
- process response,
- management involvement
- plan compliance,
- communication index
- conflict index, and
- information sharing index.

In order to compare the performance of different CE projects, “normalizing metrics” can be used. These compare the product Complexity, such as number of functions involved, number of components, number of team members and managers that really know how the product works and project Capability, such as number of people involved, number of teams, management organization and dispersion of teams and their members.

#### Implementation Framework

CERC and other implementers of CE have established processes that encompass many of the

lessons learned listed above. Combining these processes provides a framework for a CE Implementation Plan.

The framework is

1. Train Top Management - CE and Team Dynamics/Skills.
2. Establish CE Steering committee.
3. Select Potential Team Members.
4. Train Potential Team Members and Functional Managers - CE and Team Dynamics/Skills.
- 5 . Perform CE Readiness Self-Assessment
6. Determine required changes and improvements to be ready to implement CE.
7. GO -NO GO decision.
8. Initiate required Organizational and cultural changes.
9. Assign a Steering Committee member as Pilot Project Sponsor.
10. Select Pilot project
11. Create Cross-functional Team.
12. Team designs Team Operating System.
13. Current Product Process Captured and Analyzed by Team.
14. Team develops Team Metrics.
15. Team decides CE Tools to be used.
16. Team develops Pilot Project Plan.
17. Team presents Goals, Metrics and Plan to Sponsor and then Steering Committee.
18. Perform regular Self—assessments of Team Performance against selected Goals, Metrics and the Plan.
19. Apply ‘lessons learned’ to other projects to continually improve the CE Process.

#### INFORMATION SYSTEMS REQUIREMENTS FOR CONCURRENT ENGINEERING

A generic information system is impossible to precisely specify for Concurrent Engineering. This is because each business entity, and specifically, a shipyard, has its own unique legacy systems in operation. These must be individually accounted for and realistically optimized for return on investment. Therefore, it is only possible to broadly describe the information system attributes that a shipyard should consider in implementing a Concurrent Engineering methodology. These will include systems able to communicate with each other, as well as with customers and suppliers systems. The systems must maintain accurate and controlled records of all



transactions, design reviews, production schedules, problems, and issues. They must provide data to the entire Concurrent Engineering Team in real-time as requested.

An appropriate information system must be adaptable to evolutionary changes. It should be no more rigid than the engineering and manufacturing process it is designed to control. The design environment of tomorrow must be "Accessible, Flexible, and Open." An open environment is the ability to handle a heterogeneous set of design tools, that is, the ability to handle co-designs by combining or linking tools from different disciplines together. This is called Integration Software.

Information links in most U.S. shipyards between engineering and manufacturing are still sequential. In advanced companies, research product development and the design of manufacturing processes are carried out concurrently so that knowledge from one area can readily influence decisions made in other areas in real-time. An information system must be capable of Parallel interfacing and simultaneous information sharing. The objective is to provide a seamless, homogeneous flow of information to all interested parties who have the ability to react and interact in real time.

The impact of concurrent engineering emphasizes the design through the build integration cycle of the overall product and process. New information systems are needed having ability to access this information. New access methodologies must be developed that also attempt to develop layers of information. Systems need to provide the ability to access bits and pieces at higher macro levels so that the teams can recognize whether the data stream has value. The concept of Information Systems has changed from one of management control to one of information sharing.

What is needed is cost effective solutions to sharing information based on reduced time to market (product introduction cycle time), a "do-it-right-the-first-time" attitude (design quality), and a focus on involving all organizational functions all the way through the product cycle (information constantly shared cross-functionally). The data processing characteristics of the personal computer with the transaction-processing capabilities of today's mainframes need to be connected. The extreme maintenance costs of computing must be lowered and the productivity realized by their use increased. An information strategy must be put into place. Information organizations must be driven. They should not be the drivers.

The approach of choice, is an *Open System*, designed for *Accessibility, Flexibility, Parallel Interfacing, Relational Data Base Storage*, and *Libraries of Information* for Technology Re-Use. *Application Frameworks* also to allow for multiple application software and mixed CAD/CAM/CAE tools, with some degree of access and monitoring should be included in

*any CE IS System. Interoperability, scalability* for the future, and *availability* to cross-functional inquiries are key attributes. The ability to *set standards for application* and change hardware as capability needs warrant (speed storage, network server needs, etc.) are other key attributes.

Therefore, the recommendation for a CE Information System will most likely require a paradigm shift to an *Integrated Client-server Information System*.

## COST BENEFIT ANALYSIS

Actual cost benefits of CE are not widely shared. This is understandable as it may be either an embarrassment to a company, if not good, or a competitive advantage to a company, when it is good. It may also because they are not easily measured, especially with normal accounting methods. Activity based accounting should help but only if the activities are set up for CE.

Cost benefits are reductions. The reduction can come from the direct benefits of improving a design, better material selection and work content reduction as well as the indirect benefits from shorter product development cycles. For the latter, there are obvious cost benefits from the application of known fixed costs and other overhead costs due to the shorter duration to which they are applied. But there are also unknown cost benefits from getting to the market quicker, better quality, greater customer satisfaction, etc., which are difficult to assess.

Most proponents acknowledge overall cost reduction from the use of CE, mainly due to reducing product cost through better design and eliminating rework due to bad design decisions and design errors.

An attempt to develop better knowledge of the cost impact of CE was performed by TRW (Nichelson, 1991). They looked at four different products on which some of the CE approach was used. It can be seen that the Benefit/Cost ratio increases directly with extent of CE applied and also with number of personnel involved. The latter is surprising as CE could be expected to become more difficult with larger groups. On the other hand, it may be because the implementation of CE results in a structured approach with tools to improve the factors that normally become more difficult with size, namely, sharing information communication, etc. Benefit/Cost Ratio varied from 2.8 to 8.6, which are very significant.

## IMPLEMENTATION OF CE AT BATH IRON WORKS CORPORATION

As with most shipyards, elements of CE have been part of the evolving product development process at BIW for a number of years. In particular, past focus has been on involvement of shipyard planning and production engineering functions in the design process,

overlapping design and production phases of product development, application of enabling technologies such as CAE/CAD/CAM, and more recently the use of teams in management of the product delivery process. In addition to the CE pilot described in this paper, a number of other ongoing projects at BIW have implemented best practices identified through CE benchmarking and technology transfer with industry leaders. The CE pilot described herein represents an intensified and focused effort to implement all of the essential elements of CE within a single project and to thereby lay the foundation for broadened understanding and institutionalization of these practices throughout all future product development efforts.

## SELECTION OF A PILOT PROJECT

The CE Pilot implementation began with the evaluation and selection of a pilot project in December, 1993. Numerous candidate projects were ongoing or proposed including barge mounted electrical power generating plants, lubricating oil purification modules for shore-based electric plants, a small coastal combatant ship, a MARITECH funded multiple ship design project and a major upgrade to the DDG 51 class destroyers presently under contract.

These projects were evaluated on the basis of several criteria including project size, manageability, required level of effort breadth of scope, duration, significance in relationship to other shipyard projects and affordability. The project had to be small enough to be manageable, i.e., the size of the effort had to be such that if obstacles were encountered there would be some flexibility in managing the impact on resources and other projects in the shipyard. A significant emphasis was placed on the need for shipyard control of the design and product delivery process. It was recognized that if external constraints were too rigid, either in terms of product specifications or contractual requirements, that the potential benefit of the project would be compromised. Counter-balancing the need for manageable size was the need to have the scope and nature of the project recognizable as a significant undertaking in terms of complexity, technical challenge and importance to the shipyard. It was desirable that the duration of the project be relatively short in order to produce measurable and -identifiable results. The overriding constraint in all cases was that potential projects had to be funded and approved by senior management.

As expected, none of the candidate projects met all of the above criteria. The most difficult criteria to balance was the need for significance versus the desire for short duration. Of the significant shipbuilding projects considered, all were expected to span more than a year's time, due to the basic nature of large shipbuilding projects - size, complexity and level of

effort - and the fact that contracts with specific commercial customers had yet to be developed.

A meeting was held in December, 1993, at which BIW managers met along with the NSRP Applications team to decide which of the candidate projects would become the CE pilot. At this meeting it was decided that the recently awarded MARITECH design project offered the best prospects for successful implementation. Factors which favor the selection of this project include it is recognized as significant work for the shipyard, external constraints are manageable, risk to other ongoing projects is minimal, scope is broad, involving all phases of ship design and construction, and funding had been obtained.

A key issue on which a compromise had to be reached was the probable duration and scheduled start of actual CE implementation relative to the desires of the NSRP. It had initially been desired that the pilot be complete within one year from the start of the NSRP project. In the case of the selected CE Pilot, the duration of the project would necessarily be prolonged due to the relationship between it and the larger MARITECH "focused development project" through which it is funded. The MARITECH focused development project involves not only the development of multiple ship designs but also development of facilities modernization plans, commercial ship financing plans and technology transfer between BIW and two foreign shipyards, Kvaerner Masa Yards (KMY) and Mitsui Engineering and Shipbuilding (MES). As such, the implementation plan schedule and duration of the CE pilot has had to adjust to fit within the framework of these other activities.

## MARITECH FOCUSED DEVELOPMENT PROJECT

The objective of the MARITECH focused development project at BIW is to achieve re-entry into the commercial shipbuilding market. The last commercial ships built at BIW were delivered in 1983. Product development efforts since that time have focused almost exclusively on military combatants for the U.S. Navy. As previously alluded, the MARITECH project focuses on developing essential capabilities in all areas of the ship design and production process necessary to re-enter the commercial market. These areas include: design, construction, facilities, human Resources, contracts and financing.

The first step in this effort has been the definition of specific capabilities and technologies required in each of these areas. This has been approached by conducting in-depth studies of two world leading shipbuilders, Kvaerner Masa Yards (KMY) and Mitsui Engineering and Shipbuilding (MES). Several teams of individuals representing all functional areas of the company were involved in bench-marking of these two companies. A total of 45 BIW employees were involved in these

exercises. The result is a very broad and thorough understanding of the work methods, procedures, technical and administrative systems management practices and productivity at all levels of these two world -class shipbuilders.

The knowledge gained through these bench-marking exercises is being applied through a team effort coordinated by a Commercial Shipbuilding Project group comprised of representatives from all functional areas of the company. Members of this team, co-located within the shipyard, are responsible for developing ship designs, shipyard facilities plans, ship construction plans, marketing plans, contract and financing arrangements, human resource and training plans.

Obviously, ship designs and construction plans have no use if they do not serve a viable market with known prospective customers. One of the principals of CE is to involve the customer directly in the development of new product designs and delivery strategies. In the case of the MARITECH project, two prospective customers were identified at the outset. Both are ship operators that presently own and operate ships in the commercial vehicle transport trade. Both were approached and agreed to cooperate with BIW in developing the initial MARITECH project proposal and to participate as partners in the subsequent product development effort. The direct participation of the senior management, technical and operations staffs of these potential customers in the CE process has been essential to achieving the goal of direct and ongoing customer interface throughout the product development process. In addition, marketing surveys and participation in important industry conferences and technical symposia are also means that are being used to achieve this goal of the CE effort.

## IMPLEMENTATION PLAN

The CE Pilot effort is broken down into several principal phases Team Selection, Team Training, Management Training, Product Delivery Strategy, 1st Ship Design, 1st Ship Production, 2nd Ship Design, 2nd Ship Production. ongoing and in parallel with this activity is the technology transfer between KMY and Mitsui previously described. The ships being designed are RoRo vehicle carriers. Each design has unique requirements in terms of required cargo capacity, handling and stowage capabilities, deadweight tonnage, service speed and limiting drafts.

Completed work on the CE Pilot thus far includes team selection, team training, management training and development of a product delivery strategy. Presently ongoing is the contract design for the 1st Ship Design. The initial phases of technology transfer with KMY are complete. Subsequent activity will involve on-site visits by members of KMY staff to BIW. The initial

bench-marking of MES took place during February of this year. On-site technology transfer will occur over the next several weeks at MES. Subsequent activity with MES will be determined based upon the outcome of these next on-site visits.

## TEAM ORGANIZATION

As discussed earlier, there is as yet no established organizational model from within the shipbuilding industry to follow in determining the composition of a shipyard CE team. Reported U.S. shipyard CE experience has focused primarily on "enabling technology" - CAD product models, distributed databases, document and work flow management systems - as opposed to CE team organization. This is also true with respect to foreign shipyards which have, for the most part not adopted a formal CE approach in their product development processes, at least insofar as establishing CE team organizations distinct from the line organization.

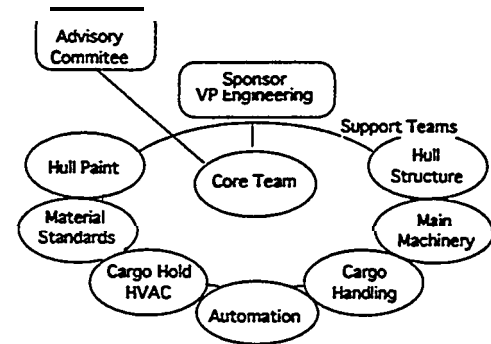


FIGURE 6 - CE PILOT TEAM ORGANIZATION

The "core team," "support team" organizational approach is being applied in the CE pilot-at BIW. A core team has been formed to provide overall guidance and direction to the project effort. Support teams have been formed to coordinate and consolidate support from within the line organizations. Figure 6 depicts this structure. Core team members have "custodial" responsibility for representing, interacting with and directing support team activities.

In addition to the team structures, a senior management sponsor and advisory council have been designated to provide oversight, accountability and direction to the core team. The role of these groups in the CE process are further described below.

## CE TRAINING

Training of the CE team is an essential element of implementation. In BIW'S case, considerable effort had been made over the past several years to provide broad-based training in team problem solving techniques. In-house training programs include one to three day courses providing instruction in team process orientation management leadership and specific matters relating to the ongoing transition from trade to multi-disciplinary work teams in production. This training can provide useful background for participants in a CE process, however, it provides only one of several skill sets that are essential to a competitive product development team. Beyond basic technical design and team problem solving skills, development of skills in the following areas is considered to be essential

- Analysis of Competitive Environment
- Strategic Design
- Innovation
- Process and Product Measurement
- Team Dynamics Measurement
- Interpersonal Interaction

Extensive training material has been developed and is available from CERC and the Institute for Competitive Design (ICD), Rochester, Michigan to instruct product development teams in these areas. The ICD program has been applied in the training of product development teams at over 300 companies world-wide. As one of the NSRP project tasks, BIW agreed to apply the ICD method and to evaluate its effectiveness in preparing the CE pilot team.

The agreed upon training program was planned during a visit by Mr. Bart Huthwaite of ICD to BIW in December 1993. It focused on three areas: 1) management training, 2) product development team training, and 3) facilitating development of a Vehicle Carrier product Delivery Strategy

The product development team training program and exercises are explained briefly in the following sections.

### MANAGEMENT TRAINING

Management training began with the initial visit of Mr. Huthwaite to BIW in December, 1993, in which he conducted a CE orientation briefing in conjunction with the bench-marking exercise previously described. This briefing covered the basic principals of CE and included an hour long question and answer session in which many organizational and procedural issues were discussed. A second management training session was held on March 8, 1994. This session included members of the pilot product development team as well as Mr. Huthwaite. The product development team presented the results of the training workshop, described later, in

which they had participated. Another important element of this session was an evaluation of management confidence level in the existing product development process. The intent of this exercise was to establish a baseline against which to measure the effectiveness of the CE implementation effort. This evaluation included strategic perspective, speed, cost awareness, quality and efficiency of present product development efforts. In each of these areas, four to five specific questions relating to performance of present product development efforts were asked. Managers rated corporate performance on a simple scale of one to ten. The overall results indicated a less than satisfactory perception of the existing product development process.

### PRODUCT DELIVERY STRATEGY

The development of a "product delivery strategy" within the context of a CE process is very similar to the exercise of developing a "build strategy." The actual process involved is described below as part of CE product development team training. The result of this process is a 30-50 page document which spells out specific product attributes, metrics, action plans and responsibilities for accomplishing the development of a new product. The development of this document took place over a period of four days, from August 5-8, 1994, in which members of the product development team including ship owner's representatives and representatives from all internal BIW division participated. This process culminated in the presentation of the product delivery strategy to senior management

Specific results of this effort will be presented at the industry-wide CE workshop planned for June, 1994, in Bath, Maine.

### PRODUCT DEVELOPMENT TEAM TRAINING

Training of CE product development team, comprised of both core and support team members, was conducted by Mr. Huthwaite from January 12- 15 at BIW. Between 25 and 30 BIW employees participated throughout a period of four days. The purpose of this effort was to provide thorough understanding of the fundamental skills required of product development teams, and to provide hands on experience in the application of these skills through a series of hands-on exercises. Specifics of Mr. Huthwaite's method are described in *STRATEGIC DESIGN: A GUIDE TO MANAGING CONCURRENT ENGINEERING* [13]. In general, the format for these sessions follows a set sequence that begins with explanation of a particular technique by Mr. Huthwaite followed by discussion involving the entire group, break-up of the group into working teams, application of technique to a sample problem, presentation of results by each team, and

critique of results by the entire group. For the purposes of training the group was given the task of designing a simple mechanical device. Initially, the device chosen was one used by Mr. Huthwaite with many training groups over a long period of time. By exercising its skills in designing this simple device, the group was able to compare its results with the results of many other groups facing the same challenge. The comparisons, needless to say, were quite intriguing. The group also worked with a sample design problem representative of that which would be encountered in a typical ship design situation. The chosen example was a down-flooding device to be used in refrigerated cargo holds wherein the device would serve as an effective barrier against the pressure, temperature and humidity differences between two adjacent cargo holds as well as function reliably as a cross connection in the case of flooding.

### Analysis of Competitive Environment

For a product development team to be effective, it must have a clear understanding of the competitive environment in which it operates. This environment is characterized by

- customer's needs including
  - functional requirements
  - price expectations
  - performance expectations
  - schedule demands
- current competitive products available or under development in the market place
- external and internal constraints including
  - available capital resources
  - available technology
  - safety and environmental regulations
  - other legal or political restrictions
- internal strengths and weaknesses including
  - available skills and experience
  - shipyard tooling, facilities and capacity
  - proven capability in the market place

By tasking the product development team to analyze the competitive environment the entire team is driven to define and focus attention on what are the most important problems to be solved in the design process. In general, it is more important at the outset that the team be working to solve the right problems, as opposed to working to immediately solve any particular problem right

An effective strategy being employed by the BIW CE pilot team is to observe the operations of ship types similar to that which is to be designed. Direct discussions with ship operating crews, port facility operators as well as ship owners are essential to

understanding the competitive environment in which the ship will operate. Comprehensive data regarding the port restrictions, usage fees, insurance fees, operating and maintenance costs, crew skill, qualifications and experience are being sought. Industry trade journals and reports of pertinent regulatory agencies have been reviewed, compiled, analyzed and condensed. A strategic goal of this effort is to consolidate a technical library of ship designs to serve as design performance benchmarks in the development of new ship designs.

To understand its own competitive strengths and weaknesses, it is necessary for a company to view itself from the outside looking in. Bench-marking of competitors is one way to gain this perspective. Considerable recent research and attention have been devoted to analyzing the general competitive strengths and weaknesses of the U.S. shipbuilding industry. This work can serve as a useful starting point in developing techniques for analyzing and quantifying its own specific strengths and weaknesses. The use of consultants to obtain a third party opinion may also be of benefit.

### Strategic Design

The analysis of the competitive environment provides a rational basis for defining specific fictional attributes of the new product design. Traditionally, these attributes are described in an outline specification developed by the marketing department in conjunction with a potential customer. In a CE process, other shipyard departments are involved in this process through participation in the product development team. In the CE process, the definition of product functional attributes is not limited to just external customer requirements, but is expanded to include the requirements of internal "customers" as well. The result is a set of requirements that reflects the company's strengths and capabilities and that ultimately leads to achievement of the highest quality within the competitive constraints of the market.

The process of defining product attributes in a team environment is quite straightforward. The team divides into groups, the groups compose lists of attributes, the attributes are categorized, evaluated against the company's strengths, internal and external constraints, ranked in priority order and finally selected by the team to be either included or excluded. The objective of this effort is to identify the eight most important competitive attributes of the product. These eight will become the basis for future measurement of product success. One important criteria in the selection of these attributes is that each attribute must be quantifiable in terms of some measurement of the product design, e.g., cargo deadweight capacity or the number of structural parts are both measurable attributes of a ship design.

For each product attribute, three measurements or metrics are initially identified 1) the current design

value, 2) the minimum or threshold value considered to be acceptable and 3) the objective value or competitive goal.

For a complex product such as a ship, the idea that there should be only eight attributes of the design considered “most important” created a great deal of controversy within the pilot product development team. To resolve this controversy, the technique used was to broaden or categorize the definition of the eight most important competitive attributes, and to discretely specify attributes and associated measurements within each broad category. Thus, a broad category such as maintainability could be identified as a critical product attribute but quantified in terms of several more discrete attributes such as overhaul and dry-docking interval, underway maintenance tasks, crew size, number of required spares, etc.

The essential benefit of this exercise is that it focuses the team’s attention on the attributes which are most important to the success of the product design, and provides quantifiable goals for the measurement of the design in process.

Another important outcome of this process is the definition of the “step”, “stretch” and “leap” versions of a product, representing the present version, the next incremental evolution and the future long term vision of a product. The product development team should be encouraged to look beyond present constraints and/or limitations to envision how future versions of the product will evolve. In the marine industry, for example, future requirements for safety, environmental protection, automation, etc., can be expected to have significant impact on ship capabilities. The objective of developing a design strategy is not only to identify and quantify competitive attributes of the present version of a product but to identify and plan for future development and improvement of the product. The ultimate goal is to provide for such development and future upgrade of the product in the present design.

## Innovation

The core technical skill of the product development team is its ability to innovate and develop cost effective technical alternatives to achieving strategic design goals. In world-class product development teams, this is accomplished by iteration of multiple alternative designs and rational evaluation of those designs based upon criteria that measure the total cost impact of their distinguishing attributes. It is essential that the product development team understand the total cost impact of alternative designs. This includes understanding the principals of producible designs and developing the ability to map and evaluate the process impact of alternative design solutions. In the CE process, the core team effort is initially focused on developing the technical solutions to the eight top priority competitive product attributes. In latter stages, support teams

should also apply this methodology in developing detail design of subsystems and components.

The principals elements of process based design include

- reducing numbers of parts
- simplifying manufacturing processes
- simplifying product Structure/architecture
- identifying and eliminating hidden costs.

Part number reductions can be achieved either through the greater use of “common” or “standard” components, by parts “implosion” or simply eliminating parts. Standardization is not a subject that is new to the U.S. shipbuilding industry, however, by comparison the U.S. industry clearly has a way to go in achieving the level of standardization typical of world leaders. One of the most successful strategies employed by industry leaders is the use of multi-functional materials, i.e., materials that can be substituted or applied in a variety of situations. The use of high strength steel in lieu of mild steel for equipment foundations to avoid having to stock two different grades is a good example. Parts implosion is the technique of creating a single part to accomplish the same function as previously accomplished by a number of parts. The familiar case of using stanchions to both support grating and pipe running beneath the grating is an example of part implosion. A simple example of parts elimination would be the use of shallower deck stiffening which eliminates the need for reinforcing collars in way of stiffener penetrations through web frames and bulkheads.

Process simplification is achieved in a number of ways including the elimination of process steps through simplification of the product design, and the reduction of variability and precision required in the manufacturing process. Examples of highly variable processes typically involved in shipbuilding include welding, compound curvature in plate forming and compound bends in pipe bending. Designs that make use of modularity or repeatability will by definition have fewer process steps than otherwise. Design for assembly is also a technique for eliminating process steps in the assembly process. This is typically exploited in shipbuilding by designing for on-block and on-unit installation.

Simplification of product architecture means reducing the variety of technologies applied in production. This is the corollary to reducing the number of process steps. The objective is to simplify part geometry, eliminate sophisticated material forming and joining technologies, high precision/low tolerance machining, fitting, measuring and aligning. The use of poured chocks for instance is an example of a simplified product architecture for the mounting of a complex piece of equipment

Eliminating hidden costs means identifying the various processes such as marshaling, staging, handling, tooling set-up, surface preparation and cleaning, testing, inspecting and documenting, required to enable the production of a product. The evaluation of hidden cost is often the most difficult challenge facing the product development team. The involvement of production personnel in the product development process is essential to making well informed evaluation of the indirect costs incurred on the shop floor.

## Product and Process Measurement Skills

The total cost associated with a given design is identified and understood by thoroughly examining the process steps involved in the production of that design. Many techniques have been devised to enable such analysis, including Quality Function Deployment ICD/FOCUS methodology, Taguchi Methods, Boothroyd Dewhurst's Product Design for Assembly, GE/Hitachi Assemblability Evaluation Method and Lucas Engineering's Design for Assembly. A summary of these methods and further bibliography is provided in *DESIGN FOR COMPETITIVENESS*, by Huthwaite, 1992.

In evaluating the total cost of alternative designs, it is essential to include not only the direct labor and material cost, but also the indirect or hidden cost. The ICD/FOCUS methodology accomplishes this through a common sense approach. The method enables the CE team to quickly and comprehensively identify the process steps involved in supply, pre-production, production and post-production stages of the product life cycle. All significant cost contributors are identified including numbers of parts and part numbers, manufacturing technologies, *process* steps and indirect costs or processes. An index is calculated based on the material cost, the number of parts, the number of part numbers (i.e., different parts), the number of pre-production and production process steps and the level of precision, variability and risk associated with the processes. This type of analysis, while time consuming, results in a rational basis for evaluating design alternatives.

A representative list of the design issues to which such techniques are being applied by the CE pilot team include:

- basic hull structural framing system and frame spacing alternatives
- structural assembly breakdown and hull block size alternatives
- hull form alternatives including flat bottom versus deadrise and faired versus knuckled bulb and skeg
- deck stiffening alternatives including bulb flats versus angle bar

- main deck girder construction including box versus tee sections
- cargo hold liner and decking material alternatives
- hoistable deck and ramp arrangement alternatives
- main engine selection and installation alternatives
- piping material alternatives
- hull paint system alternatives

## Team Organization and Decision Making

To ensure effective buy-in and participation of the line organizations, the BIW CE pilot team was carefully chosen to include the individuals that will carry a large portion of the responsibility for implementing the decisions made through the team process. The CE pilot team's relationship with the line organization is maintained through each organization's respective representative on the team. The team member has responsibility to inform the line organization manager of decisions affecting his area of responsibility. The line manager must concur with respect to the general functional, procedural and regulatory requirements to be met by the design. Cost and performance objectives must also be agreed upon. These requirements are defined and articulated within the 'Product Delivery Strategy' alluded to earlier. The team has latitude to make decisions as long as the decision fits within the boundaries of the framework defined by the Product Delivery Strategy.

## Accountability

The key issue with regard to empowering the CE team is the accountability of the team and *interaction* between the team and management. The core team must be accountable. In the present CE pilot the collective accountability of the team is to its senior management sponsor, the VP of Engineering. Overall goals and objectives are set by a senior management advisory or steering committee comprised of company Officers and directors.

The frequency upon which these groups interact is important in setting the pace for the effort of the CE team. In the present case, the pilot team meets formally with the team sponsor about once per month. The Senior Advisory Committee meets on a quarterly basis.

As alluded to earlier, each core team member is accountable to both the product development team leader and the respective line functional manager whom he/she represents. At present, it is expected that both line manager and team leader will have input to the team member's performance evaluation.

## Communications

One of the principal advantages sought in the formation of a product development team is improved communications and coordination of effort amongst team members. Collocation of team members is often viewed as a requisite to effective team formation and communications. BIW has thus far employed collocation as a strategy in the pilot implementation. An office facility has been provided wherein core team members are collocated. Additional space is available for the temporary use of support team members, visiting owner's representatives, subcontractors and/or suppliers.

It has been found thus far that collocation in and of itself does not assure improved communications unless accompanied by an effective team process, pro-active participation of the individuals assigned to the team and support from the line organization. Communications between the team and the line organization is just as important as is intra-team communications. There is presently a direct line of communication between each team representative and the managers of that member's respective line functional division. Meetings between team members and line managers must be encouraged to be frequent and spontaneous.

## Interpersonal Skills

To measure and assess the effectiveness of the team process, the BIW CE pilot team has been trained in a method of team dynamics measurement. This technique is simple in concept. The team decided upon a number of measures of effectiveness including

- Technical Skill
- Decision Making Process
- Efficiency
- Open Minded Spirit
- Leader/Team Interaction
- Communications
- Individual Involvement
- Sense of Accomplishment

The CE pilot team presently conducts its own self evaluations on the basis of these factors. Team members rank team performance in several areas within each of the above categories on a scale of one to ten. The results are compiled and summarized by an individual outside the team organization to ensure objectivity and anonymity if desired. The team meets as a group to review the results and to address performance issue and decide upon connective action.

## Tools and Enabling Technologies

The CE pilot team has been encouraged to seek and apply tools and technologies which best suite its goals,

needs, level of expertise, background and familiarity. The use of proven technology has been encouraged both within the team and on the part of BIW management. Advanced geometric modeling, and naval architectural design tools have been in use for some time and are being actively employed by the team. Thus far, the application of new technology has included advanced ship structural design optimization systems and the use of state-of-the-art statistical and computational fluid dynamics systems for performing hull form and propulsion trade-off studies. It is expected that these technologies will have a significant influence on the product development team's capability to perform a greater number of iterations on a design within a shorter period of time.

The CE pilot team has a long term objective to review, analyze and recommend new enabling technologies that can benefit future product development efforts. This objective is being pursued through the foreign shipyard bench-marking exercises and through direct contacts with suppliers. Thus far the focus has been on evaluation of integrated shipbuilding and design systems.

## RESULTS AND CONCLUSIONS

The purpose of the CE pilot at BIW is to prove the validity and benefit of CE as an approach to new product development. The pilot effort is still ongoing at BIW, so it is as yet too early to reach any final conclusions regarding these matters. To date, the CE pilot effort has been given the endorsement and support of senior management and has thus far succeeded in sustaining support of middle management ship owners and individual participants. A significant amount of work has been accomplished by a small number of individuals in developing the contract design for the 1st vehicle carrier. The ultimate success of this effort will in large part be measured by the success of the product development team in obtaining a contract with the ship owners. A further report of this project will be made at an industry-wide workshop to be held at BIW in June of 1994.

## ACKNOWLEDGMENTS

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## Absenteeism Management

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### ABSTRACT

The 1995 Ship Production Symposium theme of "COMPETITIVENESS" is very timely. Competitive forces for new shipbuilding work are fierce. Any factor affecting competitive advantage which is not pursued and wrestled into submission may be the one that causes a company to be defeated in the battle for survival.

The factor which this paper will focus on is Absenteeism Management. The severity of the absenteeism -problem for business in general is growing. In a tight market such as shipbuilding, absenteeism can be the difference that results in a company being unable to compete. Those who do not know the degree to which absenteeism **affects** business should pay close attention.

### INTRODUCTION

Absence incidence rates published by the Organization for Economic Cooperation and Development (OECD) indicate that employee absence is 5.9% of total employment for the average Canadian company, 5.1 % for the average U.S. firm. Absenteeism in shipbuilding, as with most manufacturing and construction operations, is generally well above this average.

At first glance, an absenteeism rate of 5.1 % might not seem significant. However, if these figures are translated into bottom line

rests the significance of the problem begins to come to light. Assume that absenteeism at a shipyard is comparable to the national average of 5.1% and that a typical shipyard worker earns about \$40,000 per year. Under these conditions the average direct cost of absenteeism is over \$2,000 per worker.

When indirect costs such as replacement workers, additional employee benefits, lost productivity and other factors are included, this figure doubles to over \$4,000 per worker. When the first \$4,000 of profit from every worker is taken away from overall profit and added to overhead, one can only hope the competition has the same problem.

Absenteeism is any absence that is unplanned, unscheduled and related to **any** of these three main components:

- Workers' Compensation
- Insurable Sickness      Weekly Indemnity; and
- other components - which includes absence due to dentist and doctor appointments, personal business, tardiness, leaving early and a variety of other explanations which result in a worker not being at work when required.

. When an employee is not at work, their effort must either be made up by an additional employee or their work remains undone. Sometimes the effect is compounded

if an employee is key to a particular operation (such as a crane operator) and several people are standing around waiting for a replacement to arrive.

Each component of absenteeism must be managed in its own unique way, yet “the overall approach must be consistent. How can this be accomplished? How does a company walk the tightrope between - on the one hand, assisting employees to overcome their problems and return to work followed by accommodating employees to help them stay at work - and on the other hand dismissing employees who continue to have an attendance problem? Such things can and must be done to remain competitive.

This paper discusses experiences at Saint John Shipbuilding Limited in overcoming attendance problems and reducing overhead costs through Absenteeism Management. The methods used to get absenteeism under control are universal and can succeed in any other yard.

## BACKGROUND

First, some background is warranted to gain an appreciation of the scope of the employee absenteeism problem as it existed before management decided to manage.

In 1990 the multi billion dollar Canadian Patrol Frigate contract was running behind schedule and over budget. Since this was the largest contract award in Canadian history, the situation commanded much attention from the media.

To recoup schedule delays it was determined that a workforce of 2200 hourly paid workers were required. Because over 300 workers, about 14% of the workforce, were absent on any given day a payroll of

2500+ workers was needed to maintain this level of work.

The magnitude of the problem demanded involvement at the highest levels of management. The attention given by senior management was well rewarded. For example, Absenteeism Management, in conjunction with injury prevention and claims management initiatives, has reduced annual Workers' Compensation assessments to less than half of what it was two years ago. The rate is still declining.

## A NEW PROGRAM

To tackle the problem, senior management formed an Absenteeism Management Committee with full authority to research, develop and implement a program to bring absenteeism under management control. The committee did a great deal of research on existing attendance programs, . statutory regulations, jurisprudence, etc.

In researching absenteeism programs, the committee found that there were several fundamental elements required for a successful program as detailed below.

### Senior Management Commitment

Since senior management had come to realize the excessive cost of absenteeism, they were very supportive of the required initiatives.

### Good Measurement System

The existing time card system was reasonable and gave sufficient information to start analyzing and managing attendance. However, to progress to involvement at the shop floor level, a computerized Time and

Attendance System was installed. Employees began scanning, using bar coded I.D. badges whenever they started or finished a job. Data from these scans was made readily available to supervisors at computer stations near the worksite.

### Standardized, Non-Disciplinary System

The process was implemented throughout the company based on the concept of innocent, rather than culpable, absenteeism. An employee's absence was assumed to be legitimate and without fault.

### Positive, Concerned Approach Emphasizing the Importance of Being at Work

Management delivered a clear message that the business could not operate efficiently and could not effectively compete for new contracts unless all of its employees were at work being productive. The company's commitment to help employees overcome obstacles and return to work was unequivocal.

### Attendance Management Manual

This manual was developed by the committee and issued to each supervisor and manager. The manual contains sections on the purpose of the program, basic principles, responsibilities, process charts with guidelines for attendance reviews and interviews, standard attendance management letters and the rules of employment.

### Supervisor and Manager **Training**

The Attendance Management Manual was the basis for absenteeism management training sessions. Feedback from the training

and initial implementation was analyzed by the committee. As a result the text of the manual was revised to be more effective.

### Front **Line** Responsibility

After training, supervisors and managers were held responsible for managing the attendance of their crews. Management at all levels made it clear that whenever a new member was transferred to the crew, or whenever a member of the crew was absent, the supervisor was to check the attendance record.

### Union Interface

Although union involvement was not part of the process outlined in the Attendance Management Manual, management believed the process would be more effective if the unions were involved. Often, the initial counselling by the union was sufficient to improve an attendance problem.

### Documented Attendance Interviews

If attendance problems persisted, the process required a formal meeting between the supervisor, the employee and a union representative. After a discussion of the issue, attendance concerns were documented in a standardized letter to the employee. Communication between management, employees and unions was encouraged by this interview process. The interview process and documentation are described in greater detail later in the paper.

## Continuing Guidance

The management committee remained in effect to provide continuing guidance and ensure consistency. Grievances and arbitration awards were reviewed for potential impact to the program. Actions of supervisors and managers were reviewed and discussed. As necessary, the committee met with those who were having difficulty. Although each situation was handled on its own merits, a consistent approach was assured, lending credibility to the process.

## Claims Management

Workers' Compensation and Weekly Indemnity claims were actively managed. Rather than waiting for the 'system' to return workers in good health, the company started to assist employees in overcoming problems with whatever was preventing them from returning to work.

## Modified / Light Duty Program for Reasonable Accommodation

Employees who previously would have had to stay home were provided with an opportunity to return to work at less than full capacity and gradually increase to full capability.

## Employee Assistance Referral Network

The company's efforts at accommodation and attendance management often flushed out personal problems which affected an employee's work habits. These were immediately referred to a confidential assistance service outside the company.

## IMPLEMENTATION AND PROGRESS

Once the program was in place and operating, attendance thresholds were gradually tightened. In 1990, 58% of employees had in excess of 5 % absenteeism. Today, less than 30% of employees have in excess of 5% absenteeism. Overall, absenteeism has been reduced to about 50% of what it was in 1990 and is still declining.

The relatively minor investment of management time and effort has been well rewarded. With fewer employees absent, the overall workforce has decreased without allowing any schedule slippage. While such a direct result is easy to see, many advantages of Absenteeism Management can be seen but not readily measured..

For example, the morale of many workers has increased because the company has communicated the value of their attendance at work. These workers are generally more productive as a result. Also, attendance problems are usually the result, not the cause, of an employee's problem. Once the problem is brought to the surface and resolved the employee is not only at work more often but is more productive while at work.

## MANAGEMENT PROCESS

The process developed by the Management Committee and described in the Attendance Management Manual is simple, flexible and relatively easy to administer. With an effective measurement system in place, absence data can be analyzed and acted upon. Problems can be identified by looking for three basic trends:

- patterns of absence (mondays, fridays, fishing season, etc.),
- excessive incidents, and
- excessive % absence.

When an employee is identified as having an attendance problem, a series of notifications follow. If the employee's attendance improves at any stage of the process, progression to the next step may not be necessary. The usual stages of notification are listed below.

#### Step 1- Initial Notification

The union and the employee are notified that the company has a concern regarding the employee's ability to come to work on a consistent basis.

#### Step 2- First Interview and Letter

The employee is interviewed by the supervisor and, if appropriate, the first attendance letter is issued. The first letter contains a factual account of the employee's absenteeism over a given period of time, indicates the company's concern regarding the employee's unsatisfactory attendance at work, offers assistance to help the employee overcome his or her attendance problem and clearly indicates the company's expectation that the employee come to work on a consistent basis.

#### Step 3- Second Interview and Letter

The employee is interviewed later and, if appropriate, the second attendance letter is issued. The second letter reminds the

employee of the previous interview, indicates that the attendance record has not sufficiently improved (or has deteriorated), reinforces that the employee is failing to meet a basic job requirement by not being at work regularly, notifies the employee that a non-disciplinary termination of their employment may result if their attendance record does not improve, and again offers the company's assistance to help overcome the attendance problem.

#### Step 4- Administrative Termination

A letter of termination of employment is issued to the employee due to the employee's inability to attend work on a regular basis. This letter also refers to the previous opportunities the employee was given to improve his or her attendance.

#### Program Flexibility

Some of the above steps may be repeated based on individual circumstances (ie an employee's attendance improves for a time and later worsens). The majority of attendance problems are documented using standard form letters which are part of the Attendance Management Manual. However, the program is flexible enough to deal with unique or difficult cases without compromising the integrity of the process. Such cases are usually referred to the Personnel Department for action.

### SUCCESS VERSUS PITFALLS

**The** essential element for success in managing absenteeism is the company's genuine, consistent effort to help employees overcome their absenteeism problems. The success of the program is not measured only

in the number of dismissals produced because such an approach would fail.

If evidence exists that Absenteeism Management has been used to dismiss an employee without sufficient effort to help, the dismissal will have great difficulty holding up in arbitration and will result in the company spending a great deal of needless time and money in the courts. Besides, if the employee who used to be missing from work a great deal is now insistently on the job and being productive, the company has indeed achieved the desired result. An employee who attends regularly but is not productive can also be managed, but that is a separate subject.

In some cases termination is the inevitable result of an effective Absenteeism Management process. Termination for innocent absenteeism is very difficult, with many pitfalls for an employer to avoid. The onus is always on the employer to justify the action. To ensure success, the following factors must be taken into account before proceeding with administrative termination.

- The record of absenteeism must be significantly in excess of the average of the workplace over an extended period of time.
- There must be a prognosis indicating that regular attendance in the foreseeable future is not expected. The employer can be expected to bear the onus of establishing the reasonableness of its prognosis.
- The employer must prove it has acted reasonably, without discrimination, and has treated the employee equitably.
- The employee must have been advised well in advance of termination that the company was detrimentally affected by the absences of the employee and that the employer emphasized the need for improvement.
- The employee has been clearly advised in writing that discharge could result.
- The employee has been afforded sufficient opportunity to improve attendance to an acceptable standard.
- A culminating incident has occurred where the employer has assessed the employee's attendance and considered the reasonable likelihood of regular future attendance.
- The employer must have taken into consideration the length of service as well as the prospects for rehabilitation.

## **CHARTING THE COURSE**

Such an abundance of pitfalls can make management of employee absenteeism seem like an overwhelming problem. Because it is such a complex issue, it is better to approach Absenteeism Management in stages.

Depending on the individual circumstances in different companies, some of the following stages may not be necessary. If a company is small, attendance problems can be dealt with by the personnel manager, rather than by a committee. Individual companies will have to decide what level of activity is best for them.

If appropriate, Absenteeism Management should start with a small, high calibre task team reporting regularly to senior

management. The team will gather the information needed to deal with the problem. First, the team should find out how extensive the absenteeism problem is in terms of days and dollars. This exercise will reveal the effectiveness, or ineffectiveness, of the measurement system and will assist in decisions regarding what level of resources should be applied to correct the problem.

Next, management must decide what level of absenteeism is acceptable. In the era of unending government contracts, all that was needed was to be as good as the competition down the coast. That is no longer an acceptable standard.

A company needs to be aware of the level of competition it faces and where that competition comes from. This applies not only to business the company is currently doing, but also to emerging markets that the company wishes to pursue. What level of absenteeism must the company achieve to be competitive in the desired marketplace? If absenteeism is higher at one company than another, more workers will be needed to get the same amount of work done. This manifests itself in higher bids or lower profits, neither of which will provide long term success.

After an acceptable target is found, determine why the absences are occurring. Analysis should include more than just the stated reason but should delve into underlying causes as well. Rather than safety or illness, the cause may be social, legislative, seasonal, or some other root cause.

Once the causes are determined and acceptable targets are established, the task team can be converted into a management committee with a mandate to develop an attendance management program, set intermediate goals, define action plans and

implement processes such as those described earlier.

## CONCLUSION

Employee absenteeism can be a monster that eats profits and drains employee morale. It is, however, a monster that can be brought under management control. The management system described in this, provides a valuable map which, if followed, will result in a more participative and competitive workforce.





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# **Implementing Interactive Multimedia Training**

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## **ABSTRACT**

This paper will provide a brief overview of the role of interactive multimedia in corporate training, and will discuss the relevant factors in making wise business decisions regarding the implementation of interactive multimedia (IM) within U.S. shipyards.

Despite the numerous studies and reports citing the efficiencies of delivering instruction in a multi-sensory format via a computer, shipyards have been slow to implement this technology into their business practices. The reasons for this are twofold. First the technology is still viewed as nascent and unproven. Second the business benefits are not well understood by decision makers.

This paper focuses on understanding the business benefits of implementing interactive multimedia in a shipyard environment. Case studies and success stories will be referenced for the purpose of understanding how interactive multimedia training works within the shipyard. The main thrust of discussion is towards how to properly analyze the expected return on investment and strategy for implementation of interactive multimedia within a typical shipyard.

## **RECOGNIZING THE OPPORTUNITY**

The advancement of information technology has created a wealth of opportunity for companies to improve their business and manufacturing processes. Many years ago, engineers and designers saw the opportunity to improve their job efficiencies and capabilities through the use of computers. Subsequently, computer aided design, manufacturing, and engineering systems were born. Today, shipyards and other businesses are implementing advanced CAD/CAM/CAE (Computer Aided Design / Computer Aided Manufacturing/ Computer Aided Engineering) systems into their operations and realizing dramatic improvements in design and manufacturing efficiency when compared to only a few years before. The use of CAD/CAM/CAE within major manufacturing is no longer considered a strategic advantage; it is a necessity. Those that do not use it are at a competitive disadvantage with those who do.

Similar to the opportunity that information technology created through CAD/CAM/CAE, information technology has now made possible, through interactive multimedia the ability to deliver highly effective and economical training via computer. Although the concept of delivering instruction via computer is not new, the effectiveness of the delivered instruction has greatly improved. Current hardware technology and software tools now provide the ability to engage learners with graphics, sound video, and animation, and involve them through interactive lessons and simulations.

Numerous studies have validated interactive multimedia training as superior to traditional training methods for most learning situations. One study (Adams, 1992) showed that learning gains, measuring both understanding and retention of course content, was 56% higher with interactive methods versus traditional methods. The same study also showed that consistency of learning was 50-60% better, training compression (time saved) was 38-70% faster, and that content retention was 25-50% higher. Other studies (Adams, 1992) have informally measured long term content retention 350% higher than normal training content retention, six to nine months after the course was completed. These studies point to a dynamic new way of approaching training.

In addition, numerous corporations are currently validating the fact that interactive multimedia training represents a cost savings over traditional training methods. Xerox trained 14,000 customer-service engineers with over 200,000 hours of interactive multimedia training in 1992. In doing so they realized a 30% decrease in overall training time, which translated directly into less employee downtime and, consequently, significant cost savings. Delta Airlines is projected to save \$2 million annually with an interactive flight attendant training program they implemented in 1992. Federal Express was able to reduce the time it takes to train management in quality assurance and problem solving from four days by traditional methods to only one day through interactive multimedia. Finally, Bethlehem Steel has been using interactive multimedia training since 1986, with great results. They find that this training's "zero travel time, flexible scheduling, self-pacing, high retention, continuous availability, and non-

threatening learning environment” (Educational Technology, 1992), give it a significant advantage over other training methods and contribute to the 40% reduction in Bethlehem Steel’s overall training time.

## UNDERSTANDING THE OPPORTUNITY

The same improvements in training effectiveness and reductions in training cost that the aforementioned companies are realizing can be realized by shipyards as well. Although interactive multimedia training is not appropriate for all situations, medium to large sized shipyards have characteristics that make interactive multimedia training a very attractive opportunity.

The initial cost to develop interactive multimedia is significantly higher than the initial cost to develop an instructor led course. However, once the training is developed, the cost of delivering the training is relatively small. When analyzing training costs, the real cost of delivery not only includes the cost of the instructor’s time and materials, but also the cost of the students’ time away from their presumably value-adding jobs. IM primarily creates cost savings through its ability to minimize training time, thereby increasing productive time.

In order for the relatively high development costs to be recovered by subsequent savings in delivery, companies typically must have a training need that affects a workforce that is either relatively large (500+) and/or geographically dispersed. Additional savings can be realized if a company trains on-shift in a multiple shift operation. By these general standards many medium and large sized shipyards can potentially benefit from interactive multimedia training. For these yards, a thorough understanding of the variables involved with the true costs of training is essential.

## ANALYZING THE OPPORTUNITY

The technology of interactive multimedia has been proven, the benefits have been validated, and the application to shipyard-specific subject matter has been demonstrated (NSRP 1993 Ship Production Symposium Proceedings, 1993). The application of interactive multimedia technology in training should no longer be viewed as risky and unproven. Similar to the maturation of CAD/CAM/CAE, IM training will soon cease to be a strategic advantage and will become a standard methodology.

Implementation of 3M begins by developing a decision making model which compares the costs of IM with those of traditional stand-up training. With

the cost of interactive multimedia mostly contained in front end investment the cost-savings-benefit of IM is realized in delivery. Therefore, because of stand-up training’s higher delivery costs, there must be a break-even point where IM becomes more cost-effective. This break-even point is calculated by determining the different costs associated with each training method.

Costs are divided between fixed and variable amounts. Fixed costs remain constant within an individual project. The fixed costs for IM training development include items such as course design, software development and hardware purchasing. The fixed costs for traditional stand-up training include course design content development printed training material, and presentation equipment. Costs vary between different projects based upon their scope and complexity.

“Variable costs change for the individual project. In the case of both IM training and stand-up training, the prevailing variable is the total number of employees that must be trained. In both cases the number of employees to be trained determines the total amount of productive work lost. With stand-up training, this variable also determines the total number of employees to be trained and the total instructor costs. The crucial piece of information for determining overall variable costs is the percentage of time saved through IM training versus traditional , training. At this time, the industry standard is 35%-45% time saved. The combination of fixed and variable costs provide enough information to setup a decision making model.

## Opportunity scenario

The scenario used in this generic analysis is one which most shipyards could encounter. A shipyard has determined that workers lack knowledge of shipyard fundamentals, resulting in decreased productivity. These fundamentals include: general shipyard layout shipyard terminology, basic ship construction concepts and general safety rules. Management has decided that training is needed and in turn requests a cost analysis of the potential training methods. Finally, the training department has concluded that for the amount of detail required the course needs approximately 4 hours of traditional stand-up training.

The representative costs for traditional training are shown in Table 1

<b>Fixed Costs (Traditional)</b>	
Course Design & Content Development	\$17,500
Printed Material	\$12,000
Presentation Equipment	\$2,000
<b>Total Fixed Costs</b>	<b>\$31,500</b>
<b>Variable Costs (Traditional)</b>	
Worker's Salaries (either replacement costs or from lost revenue)	\$160/worker (based on a \$40/hr burdened rate x 4 hrs. training)
Trainer's Salaries	\$12/worker (based on a \$60/hr burdened rate x 4 hrs. training / 20 students per session)
<b>Total Variable Costs</b>	<b>\$172/worker</b>

**Table I**

Representative costs for interactive multimedia training are shown in Table II:

<b>Fixed Costs (Interactive)</b>	
Course Design & Software Development	\$70,000
Hardware Requirements	\$2,500 (Assumes \$25,000 initial purchase spread out over 10 lessons [5 yrs. avg. usefulness of computers x 2 lessons/yr.] )
<b>Total Fixed Costs</b>	<b>\$72,500</b>
<b>Variable Costs (Interactive)</b>	
Worker's Salaries (either replacement costs or from lost revenue)	\$96/worker (based on a \$40/hr burdened rate x 2.4 hrs. training [estimated time savings 60% x 4 hrs. traditional training])
<b>Total Variable Costs</b>	<b>\$96/worker</b>

**Table II**

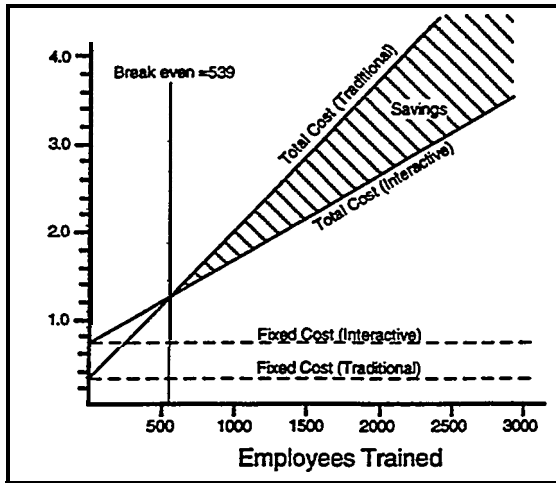


Figure 1

As shown in Figure 1, the break even point for this shipyard is approximately 539 employees. In this case, a shipyard that has training needs for 3,000 people over a span of five years would realize a cost savings of \$187,000. This is for just one course of relatively short duration. Multiple courses of longer time spans would increase cost savings dramatically, quickly reaching millions of dollars.

Possible changes to variable costs. Increases to the break-even point will occur if instructors are deemed necessary to supervise trainees while they are at their workstations in the interactive model, or worker or instructor burdened rates drop (see Figure 2). Decreases to the break-even point will occur if travel expenditures have to be added for either students or instructors in the stand-up model, a simulation is involved that takes machinery off-line in the stand-up model, or worker or instructor burdened rates rise (See figure 3).



Figure 2 - \$30/hour Burdened Rate

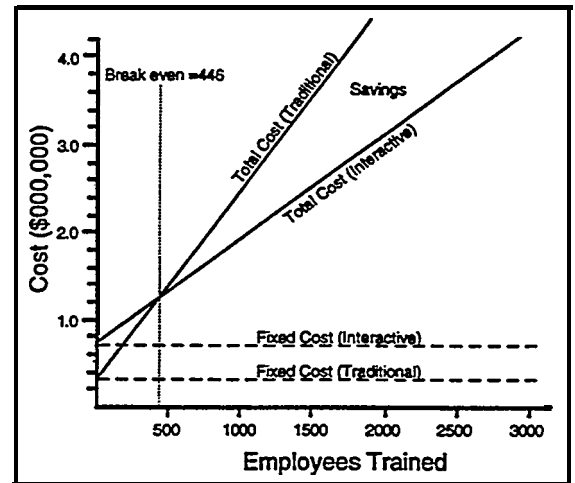


Figure 3 - \$50/hour Burdened Rate

Other considerations. Some employees needing training have not yet been hired, so the **lifetime of the training program, its ability to be updated, and employee turnover rate** are important pieces of information needed to further understand the model. Also, equipment purchased for training that is multi-purposed, or reused for different tasks later on, must be considered when tabulating fixed cost expenditures.

Further Benefits. The value of self-paced instruction, other than training compression, should also be considered. Self-paced learning affects training availability, training effectiveness, and training consistency. Training employees at the moment of need (i.e. just-in-time) results in a more efficient usage of resources. Employees who are trained consistently with high levels of comprehension of course content spend more work time being fully productive. An employee who is working at 80% efficiency because of inadequate training, is losing the company money until full training is achieved. Self-paced interactive multimedia training is the best way of eliminating this inefficiency.

## ANALYTICAL MODEL

The above example was provided to show the various pieces of information that are needed to compare the costs of traditional training against interactive multimedia training. The numbers used were based upon the averages of the current market value for the services specified. In reality, these numbers vary by location and project. The following equation is provided to be used to determine the break-even point of the two training methods.

	Traditional Training	Interactive Multimedia Training
Fixed costs	<ul style="list-style-type: none"> <li>•Content and course development</li> <li>•Printing test materials</li> <li>•Teaching aids and demonstration materials</li> </ul>	<ul style="list-style-type: none"> <li>•Software development and course design</li> <li>•Hardware costs</li> </ul>
Variable costs	<ul style="list-style-type: none"> <li>•Average burdened rate of trainees</li> <li>•Average burdened rate of trainees</li> <li>•Traveling costs per trainee</li> </ul>	
Other Factors	<ul style="list-style-type: none"> <li>•Total length of training time</li> <li>•Number of trainees per instructor</li> <li>•Training compression percentage (35-45% by most standards)</li> </ul>	

Table III - Components of the Analytical Model

Calculating the Break Even Point ( $B_e$ )

Avg. rate trainees= $A_e$

Total training time= $T_t$

Avg. rate trainers= $A_i$

Arnt. trainees per instructor= $A_i$

Travel costs per trainee= $T_c$

Training Compression Percentage= $C_p$

Var. Cost per Trainee for Traditional Training= $V_t$

Variable Cost per Trainee for IM Training= $V_i$

Fixed Costs (Trad. Tr.)= $F_t$

Fixed Costs(IM)= $F_i$

Break even point= $B_e$

$$V_i = (A_e T_t) + ((A_i T_t)/A_i) + T_c \quad (1)$$

$$V_i = A_e T_t ((100 - C_p) \%) \quad (2)$$

$$B_e = (F_i - F_t) / (V_t - V_i) \quad (3)$$

#### IMPLEMENTING THE OPPORTUNITY

Once an analysis has been performed that indicates that interactive multimedia will save money, a plan of implementation must be developed. Ideally, the plan of implementation will be based on a long term strategy for implementing IM in a shipyard. However, in order to make a long term strategy a reality, upper management must first "buy-in" to the concept.

There are four steps involved in introducing interactive multimedia into a new environment

- undertake a small scale pilot that demonstrates that cost effective, custom IM can be developed and delivered within that yard

- use the cost savings data collected from the pilot to obtain upper management buy-in for further IM implementation;
- create a long term strategy for implementation, and
- begin implementation.

#### The Pilot

Despite the evidence and demonstrations that shipyards have been presented with that point to the benefits of interactive multimedia, it is best practice to test the water before jumping in with both feet. A small scale pilot project should be undertaken as a precursor to further, more widespread, development of interactive courseware. Ideally, the project should

- focus on achieving a well defined training goal,
- address a subject that is relevant to current training needs,
- have an overall development time of less than 3 months, and
- generate data to measure the project's success.

The pilot project's main goals are to familiarize the shipyard with multimedia development and delivery, while limiting their exposure to risk (i.e. unrecovered investment). This familiarization is intended to occur on many levels. First, those directly involved in the project will see, first hand, the issues faced in multimedia development and implementation. Next the training recipients will experience, perhaps for the first time, interactive learning. Finally, and most critically, decision makers will see the finished product and assess its business benefits based on the generated cost savings data.

A pilot project will require relatively high visibility in order to achieve its goals, so it is best to minimize the chance of failure by selecting subject

matter that is well understood and a scope that is well defined. This does not mean that the subject matter should be of trivial importance. It is important that the pilot be designed to address a real life training challenge in order to generate meaningful and credible data.

The scope of a pilot project should be such that the overall development time (the time a project team is first assembled to the time a final product is delivered) does not exceed three months. The three month time limit creates a sense of urgency, which discourages a bureaucratic, management by committee approach, and contains project costs at a reasonable level. A pilot should not be an academic case study; it should be a brisk trip through the IM development-delivery cycle, meant essentially, to break the ground for further development.

### **Obtaining Management Buy-in**

Regardless of what subject matter is chosen, and what training need is addressed, the salient issue at hand is to determine whether the interactive courseware reduces costs relative to traditional methods. It is this information that will most significantly influence top decision makers. Therefore, monitoring of a pilot project must be designed to provide top decision makers with information that validates the claim that interactive multimedia training will save their yard money.

Precise statistical measurements of a pilot's effectiveness are not necessary for the information to be useful. The relevant point is that the results observed during the pilot concur with published reports on the effectiveness of custom interactive courseware developed elsewhere. With good information in favor of the use of IM, the logical choice for decision makers to make will be in favor of interactive multimedia. However, significant changes do not occur quickly, and one should expect a certain amount of "courtship" time in which decision makers become comfortable with interactive multimedia training.

### **Creating a Long Term Strategy**

Once the appropriate decision makers have released the necessary approvals and resources to support continued IM training development, a long term strategy should be developed. The long term strategy should include considerations of the following three issues:

- consideration of IM in all training analyses;
- in-house or outsourcing IM development; and
- creating IM development and delivery standards.

After implementation of interactive multimedia into a shipyard's training environment has been effected, the method for analyzing training solutions

must be changed to incorporate considerations for IM. All new training requests should be analyzed to determine which method of instruction, including interactive multimedia, is most economically and instructionally effective. Similarly, existing training efforts should also be analyzed. The prevailing variable that determines the cost effectiveness of IM is the number of workers trained over the life cycle of the training material. Even though training material exists on a certain subject, conversion of this material to interactive format may be warranted when the future life cycle is considered.

Following an analysis of training delivery methods that recommends IM, a plan for developing the interactive courseware should be developed. Depending on a shipyard's projected need for interactive courseware, the talent to develop the material should be either acquired in-house, through outside consultants, or a combination of the two. Typically, companies tend to ease into IM development by initially relying on outside consultants for development of courseware. As time progresses, many companies tend to bring a "skeleton crew" of IM developers on in-house to handle course maintenance and small, quick turnaround projects, while still relying on outside consultants for help with major development efforts.

Regardless of whether IM is developed in-house or by outside consultants, the shipyard will have to determine the development and delivery platform that is best suited for their environment. In considering hardware for development and delivery, the equipment should:

- integrate easily with existing information systems
- meet performance needs
- upgrade to future requirements

### **CONCLUSION**

In the recent past, interactive multimedia was viewed as a risky and unproven technology. Now, there is sufficient information available to prove that this technology is viable in its ability to dramatically reduce training costs in a number of corporate environments. Multimedia has proven its validity in the corporate world. The question has now become not why to implement, but when to implement.

A model for analyzing the cost savings for interactive multimedia has been presented in this paper. The steps for implementation have also been discussed. It is now in the hands of shipyard decision makers to analyze their current training needs and determine the suitability of interactive multimedia within their individual yards.

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# Marketing Strategy for Merchant Shipbuilders

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## ABSTRACT

Much has been published over the years about technology and productivity in shipbuilding, and much also about the shipbuilding market and its potential. Little has been published to-date however, about the all important techno-economic interface between the two.

This paper sets out to explore this interface, and to identify how a shipyard can be matched to its external environment through the adoption of a coherent strategy. The elements of external forces are considered (in particular prices and market volume), and the internal factors within the control of a shipyard are examined to review how they can be utilized in a strategic sense to match a shipyard to a targeted market sector.

The elements reviewed include

- Prices,
- Exchange rates,
- Physical constraints,
- Capacity
- Market volume,
- Production characteristics and
- Shipyard organization.

## INTRODUCTION

"Consumption is the sole end and purpose of all production and the interests of the product ought to be attended to, only so far as it may be necessary for promoting that of the consumer."

(Adam Smith "The Wealth of Nations"  
- 1776).

Over the past decades, much effort and expenditure has been directed at performance improvement in shipyards, with the aim of reducing costs. This has particularly been the case in higher cost countries with shipyards seeking to offset wage rests against productivity.

Performance is about much more than just productivity, however. Whilst the number of manhours used per ton produced is of course vitally important there are other factors that have a considerable bearing on a shipyard's bottom line, some of which are outside the shipyard's control.

These factors are put into context by examining the relationship between a shipyard and its marketing environment. Whilst numerous papers have been written about performance within a shipyard and about the market outside, few have addressed the all important techno-economic interface between the two.

The marketing environment within which a shipyard operates includes internal factors, generally within the control of the shipyard, and external factors outside the control of the shipyard. The internal factors that can be manipulated to cope with changes in the external environment are normally termed the 'Marketing Mix' (Lancaster and Massingham, 1988). Generally grouped under the four 'Ps', these factors are:

- the design and attributes of the Product to match customer requirement:
- the design and attributes of the place in which production takes place, encompassing not only production attributes



but also organization and in particular overheads.

- the Promotion of the product being offered, i.e., advertising or other channels to draw the product to the attention of potential customers; and
- the Price at which the product is offered, although as Will be demonstrated later, this aspect is largely outside the control of merchant shipbuilders.

The external factors affecting the shipyard, over which it has little or no control, are numerous and wide ranging, including politics and macro-economics. The more tangible factors in the immediate environment of the shipyard (termed the “proximate macro-environment” in marketing jargon), on which most marketing strategies will concentrate, include the following:

- Market Price,
- Competition,
- Wage Rates and Costs,
- Exchange Rates, and
- Demand.

When considering these factors it should be kept in mind that the external environment presents not only the threats against which a company has to react, but also the opportunities of which it can take advantage.

It is important to understand the way in which a shipyard interacts with its environment, as well as the elements of strategy available to a shipyard in seeking to match the attributes of the market. Decisions relating to production must take into account a global strategy, including reference to the external environment and not simply be based on a continuous drive to minimize manhours.

## HISTORICAL BACKGROUND

For much of the past 10 to 15 years, commercial shipbuilding has not presented an economic opportunity for most of the world’s shipbuilders, however productive they might be. The market collapsed following a peak of newbuilding in the mid 1970s, and has remained at a low level for more than a decade, as shown in Figure 1.

The depressed level of capacity utilization

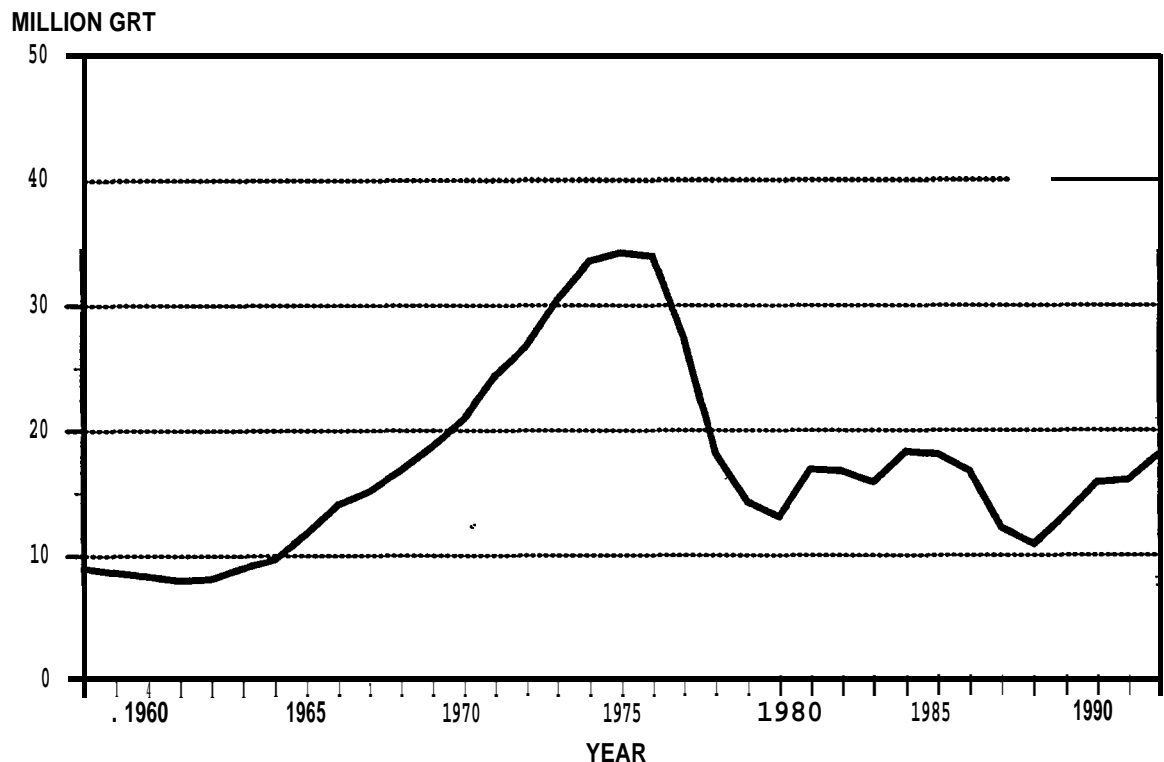


Figure 1: Merchant Ships Completed

DEADWEIGHT INDEX (1987 = 100)

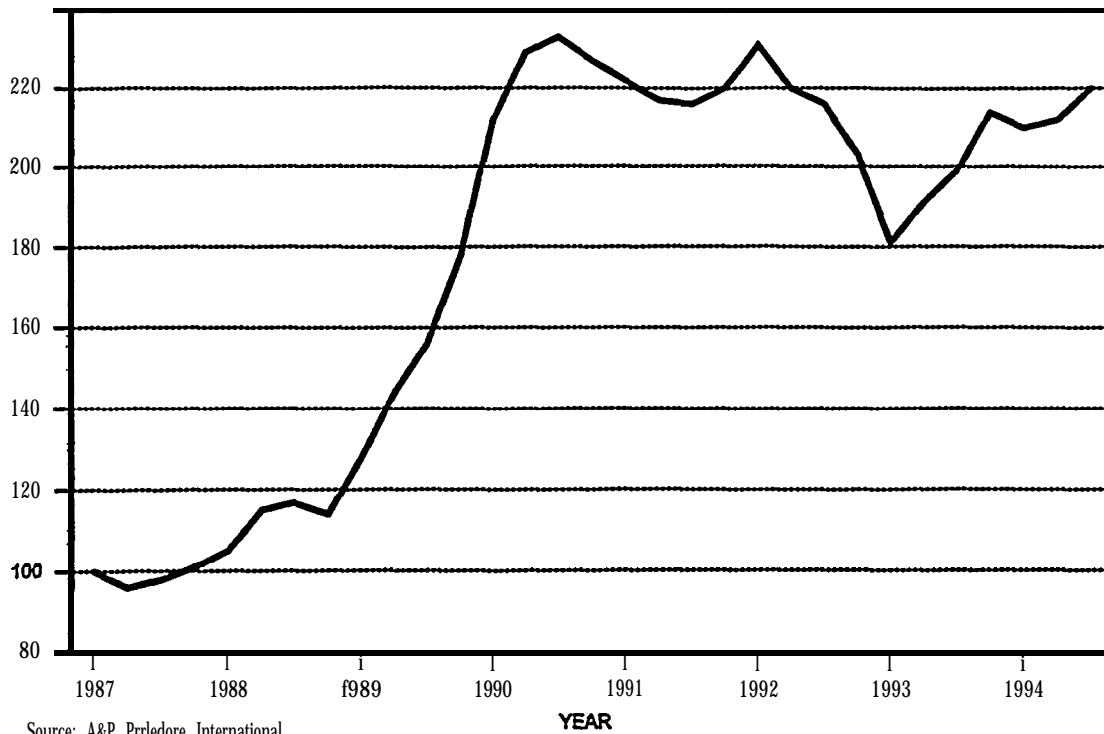


Figure 2: Orderbook Deadweight index

PRICE INDEX (1987= 100)

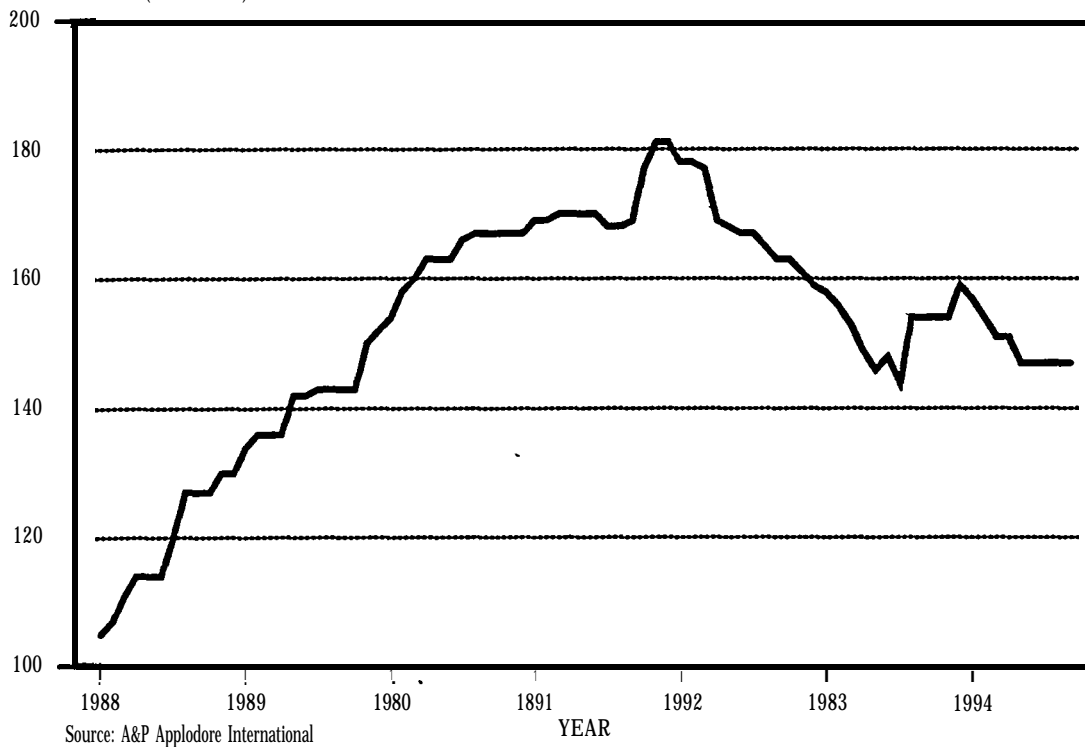


Figure 3: Newbuilding Price Index

during this period, with correspondingly low prices, led to the closure of numerous shipyards (or in some cases entire national industries), with those shipyards remaining requiring government support and intervention to survive.

Since around 1987, however, the level of international ordering has picked up, with corresponding improvements in capacity utilization and prices. (Figure 2 presents the growth in orders since 1987 and Figure 3 the development of prices over the same period). Following the period of extended restructuring and rationalization, the industry is well placed to absorb this increase in demand without the massive degree of over-capacity seen at the start of the last decade. Having said this, prices have yet to rise to a point such that much of the world's shipbuilding industry can reliably generate a profit and subsidies are still common practice in many countries.

Demand for new vessels is generated primarily by the need to replace obsolete, aged tonnage, which has reached the end of its economic life, and by the need for the fleet to expand to accommodate growth in trade. In addition to these two primary determinants, demand for new vessels is also generated by technical developments, such as the development of containerization, or by legislative pressure, such as the implementation of OPA90 in the USA which discriminates against aging, single skin tankers.

These factors are illustrated in Figure 4, which presents a simplified diagram of the shipbuilding market and the shipping market (Note The second hand sector of the shipping market has deliberately been left out of this diagram for the sake of clarity. For a full description of the economics of the shipping trades, the reader is referred to Stopford, 1988).

As a consequence of the lack of newbuilding between the mid 1970's and the late 1980's, the average age of the fleet is high, at around 17 years. In the face of an economic life expectancy of between 20 and 25 years, the prospects for fleet replacement in the coming decade are good, particularly when coupled to escalating concerns amongst governments, charterers, insurers and classification societies about the large volume of aging and

sub-standard tonnage currently trading. A second consequence of the historic lack of newbuilding has been that much scrapped tonnage has not been replaced and the level of surplus tonnage within the fleet and thereby its ability to absorb fluctuations in demand, has been reduced and growth in trade therefore leads more directly to demand for new tonnage.

Against this background, most forecasts of newbuilding for the coming decade are optimistic and shipbuilders are gearing up for improved demand, although it has to be said that there are structural problems in all sectors of the market that could cast a shadow over the awaited recovery. These factors are discussed in full in Peters, 1993. This potential opportunity has arisen at a time when many shipyards are looking for opportunities to replace declining workloads for warships, following the so-called "peace dividend".

This is the situation to a large extent in the United States. Most US shipyards **have not been** active in the international commercial sector for

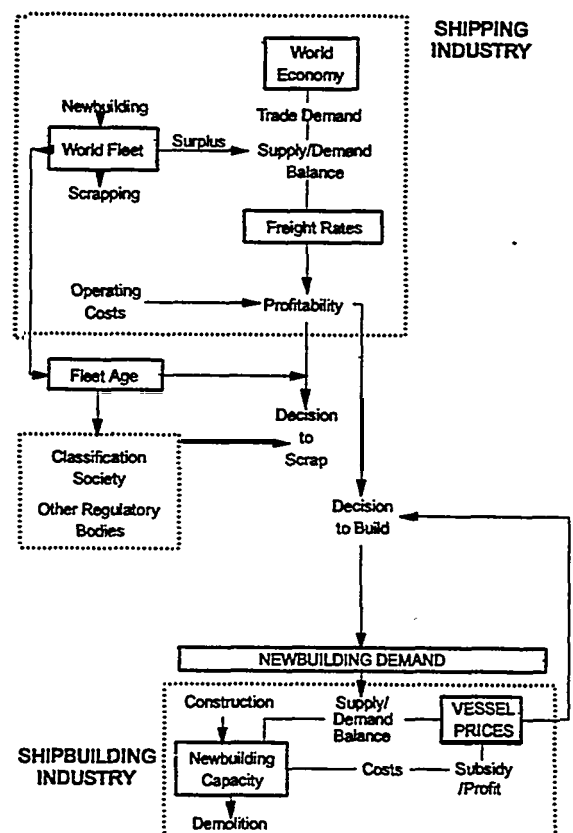


Figure 4: Market Drivers and Key Determinants

some years, and are currently seeking ways to capitalize on the potential for commercial newbuilding.

In reality, a shipyard does not operate in isolation and does not have a free hand to construct whatever it chooses. The environment (in the broad sense of the word) imposes constraints within which a shipyard must operate and which will dictate at least partially the range of ships that may be included in its product mix.

## THE CORRECT STRATEGY?

When faced with a blank order book a shipyard must make a decision as to the market sector to be targeted. This decision has often in the past been made intuitively, due to lack of defined methods or constraints against which to analyze the product mix.

Successful entry into the merchant shipbuilding sector will be a matter of strategy. The era when shipyards could aim to construct all types of vessels according to market demand has finished, and most shipbuilders now specialize. This enables organizations and facilities to be correctly matched to the target market sector. The strategy requires very careful consideration, especially because it is easy to get it wrong.

A good example of a common intuitive strategy is one that would aim to build sophisticated ships, to capitalize on high levels of technology in the high wage cost countries. This seems to be a perfectly rational approach and is one that has been adopted in the past in particular in some European shipyards but some of the underlying assumptions require careful consideration.

Firstly, this strategy **wrongly** assumes that the price of a ship is related to its work content. In other words, that a more sophisticated ship will attract a higher price. This is unfortunately not true, as can be seen from Table 1, comparing a sophisticated container ship with a more simple panamax tanker.

The income per unit of work as measured by compensated gross tons (Kattan and Clark, 1993), is higher for the less sophisticated, larger ship than for the container ship, despite the seemingly attractive higher price of the former smaller vessel. To be rigorous the added value rather than price should be compared to work content. After subtracting material costs, the relative numbers become \$750 added value per unit of work for the tanker, and \$665 for the container ship.

Ship prices move on a commodity basis, rising and falling with supply and demand, as can be seen by studying Figure 3, the price index. The price is, in general, not within the control of the shipyard.

Secondly, the strategy outlined above confuses the sophistication of the product with the sophistication of the process. A passenger ship is a good example of a sophisticated ship type that uses a high level of traditional and labor intensive shipbuilding skills. Series building of simple bulk carriers, on the other hand, permits the maximum utilization of sophisticated automated processes and robotics, making best use of advanced production technologies available in developed countries. It also minimizes labor content where labor cost is a disadvantage.

	2,500 TEU Container Ship	80,000 DWT Tanker
Price (February 1994)	\$45 million	\$44 million
Gross Tonnage	37,000	46,000
Compensated Gross Tonnage	27,750	25,300
Income per CGT	\$1,621	\$1,739

Table 1

The most appropriate strategy may, in fact, be counter-intuitive and its derivation requires very careful thought with respect to a number of factors.

## ECONOMIC INFLUENCES

The implications of price not being within the control of the shipyard requires further study. A survey of potential shipowners was undertaken recently by the author to investigate the attributes that make up a marketable design, and buyer values. The following attributes were reviewed:

- Price,
- Delivery,
- Financing,
- Minimum Crew,
- Ease of Operation,
- Ease of Maintenance,
- Speed,
- Fuel Consumption/Economy,
- Capacity,
- Efficient Cargo Handling,
- Safety,
- Design/Operational Considerations, and
- Other Factors.

Whilst many of the design attributes were seen as having a positive benefit on the marketability of a design, owners (within reason) were not willing to pay a premium above the market price to reflect performance attributes. In other words, the quality of the design of a ship may be reflected in the probability of attracting a sale, but not in the price.

The effect of fluctuating prices is compounded by another factor outside the control of the shipyard : exchange rate fluctuations. These fluctuations can have a very significant effect on the economic performance of a shipyard that is almost totally outside management control. These effects are demonstrated by the following financial calculations, considering the all important but simple gross margin calculations. (Wames, 1984).

Table II presents an example of a simple gross margin calculation, taken from an actual case

Price	\$19.4 million
Labor Costs :	\$6.1 million
Material Costs :	\$10.5 million
Overheads :	\$ 1.0 million
Profit	\$1.8 million
●Including associated overhead costs	

Table II

A 5% fall in price (around \$1 million) leads to a fall in profits of over 50%, and a fall of 10% leads the shipyard into a marginal position. Conversely, a rise of 5% leads to an increase in profit of over 50% and a rise of 10% leads to more than double the profit. A quick glance at Figure 3 shows that price fluctuations of this magnitude are not uncommon.

To put this into perspective, compare it to an increase of 10% in productivity on the same calculation (represented by a 10% reduction in labor costs). This leads to a reduction in 'total cost' of 3% and an increase in profits of around 34%. It should be kept in mind that an improvement of 10% in productivity is not a trivial target, and is likely to require considerable expenditure of effort and possibly capital as well.

The second factor that is outside the control of a shipyard is exchange rate fluctuations.

Table III presents two examples, firstly, in yen with the price fixed in dollars, with the movement in exchange rate between January and December 1993, secondly, with the calculation undertaken in sterling with the price fixed in dollars, and the movement in exchange rates over the second half of 1992.

These calculations use selected exchange rates to illustrate a point. However, the effect is clear. In the case of the Japanese shipyard profit would have fallen from 9% of turnover at the start of the year to a loss of almost 3% at the year's end. Conversely, the profit at a UK yard would have risen from 9% to over 27% over the six month period shown, without any internal change in the shipyard.

The aim of presenting these simple and fairly obvious calculations is to demonstrate that external economics have a significant

Calculation 1: Price Fixed in US Dollars, costs in Yen			
Price (Million \$)	19.4		
Exchange Rate 1	125 Jan 1993		
Exchange Rate 2	110 Dec 1993		
Labor Cost	763 million Yen		
Material Costs	1,313 million Yen		
Overhead Costs	125 million Yen		
Total Costs :	2,201 million Yen		
Profit Calculations in Million Yen			
	Jan 1993	Dec 1993	
Income	2,428	2,141	
costs	2,201	2,201	
Profit	225	(60)	
Profit: Income	9.28%	-2.80%	
Calculation 2: Price Fixed in US Dollars, costs in Sterling			
Price (Million \$)	19.4		
Exchange Rate 1	0.52 July 1882		
Exchange Rate 2	0.65 Dec 1992		
Labor Coat	£3.17 million		
Material Coat	£5.46 million		
Overhead coat	£0.52 million		
Total Costs :	£9.15 million		
Profit Calculations in Million Pounds Sterling			
	July1992	Dec1992	
Income	10.09	12.61	
coats	9.15	9.15	
Profit	0.94	3.46	
Profit: Income	9.30%	27.44%	

Table III Effects of Exchange Rate Fluctuations

influence in shipbuilding, and can be of overriding importance.

#### STRATEGY, TARGET MARKETING AND PRODUCT MIX SELECTION

The dangers of coming to strategic conclusions on an intuitive basis were outlined above. To arrive at a considered and objective strategy, a number of factors have to be taken

into consideration. When faced with a blank sheet of paper, and the need to define a successful product mix, constraints are required against which to set targets.

The remainder of this paper discusses a number of considerations and constraints that have to be taken into account when deriving a strategy for a target product mix, under the headings listed below

- Physical Constraints,
- Market Volume, Market Share and other Market Factors,
- Production Characteristics and Organization, and
- Other Strategic Options.

#### PHYSICAL CONSTRAINTS

The simplest set of constraints to consider are the physical constraints of the shipyard : length, beam, depth of water and capacity. Shipyards can be classed according to the generic ship type corresponding to the maximum size of ship that could be constructed. This is difficult to classify exactly, due to the imprecise nature of terms but corresponds very roughly to:

- Small Ships (below 5,000 dwt),
- Sub-handysize (5,000 to around 20,000 dwt),
- Handysize/Handymax (20,000 up to around 45,000 dwt),
- Panamax (60,000 to 90,000 dwt),
- Cape Size (100,000 to 170,000 dwt),
- VLCC (over 200,000 dwt).

In general these size bands are very loose: only panamax and suezmax have an actual physical constraint and the generic terms are open to wide interpretation. The small ship sector is particularly difficult to classify. Below around 5,000 dwt the characteristics of the market change significantly and this sector forms a complex sub-market in its own right. (This paper concentrates predominantly on the market for larger tonnage).

All shipyards are constrained by size, although this constraint can of course be relaxed through investment, if a positive cost benefit situation is identified. In general terms, larger shipyards have an advantage. This is not

	Handymax Tanker	Panamax Tanker
Estimated Current Price*	\$33 million	\$42 million
Estimated CGT	15,120 tonne	22,160 tonne
Income per CGT	\$2,182	\$1,895
* July 1994		

Table IV

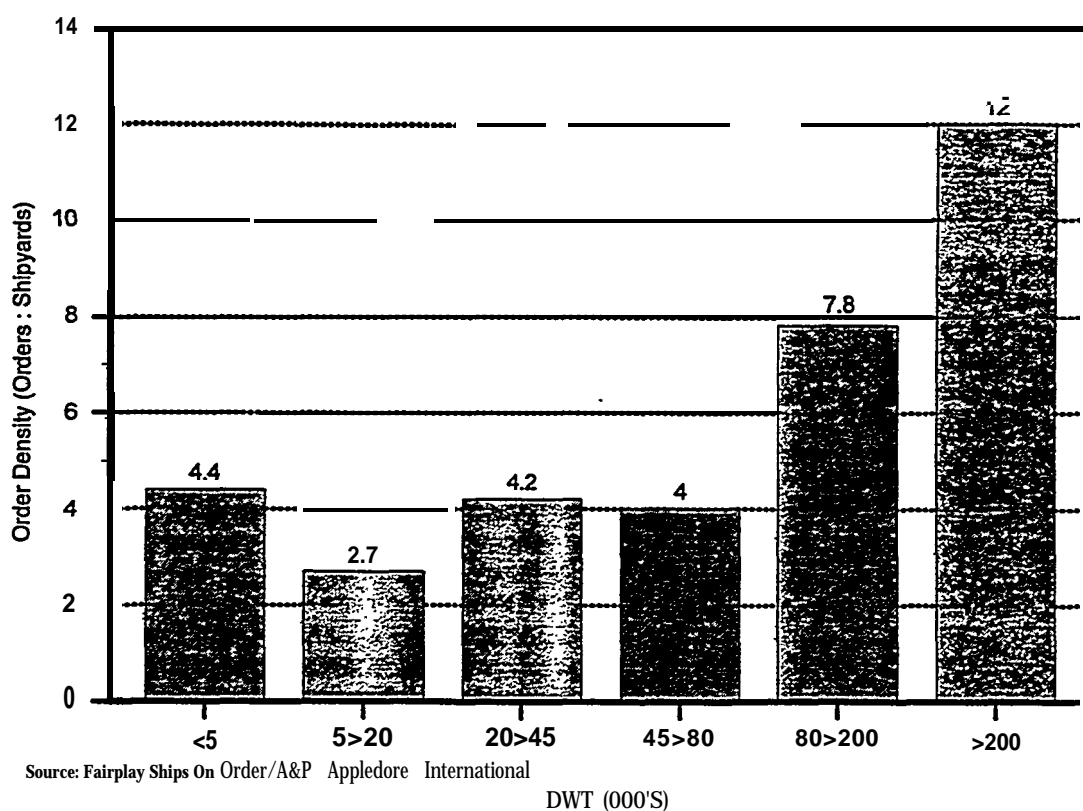


Figure 5: Order Density in the Tanker Market

because larger ships necessarily attract higher value as demonstrated by the calculation presented in Table IV comparing the income per unit of work (represented by the Compensated Gross Ton) for a handysize and a panamax tanker.

Market conditions for the handymax ship at the time of writing this paper are significantly better than in the panamax sector, so handymax ships attract a correspondingly better price.

The advantage for the larger shipyard lies in the fact that it can "trade down" to build smaller vessels, if that is what the market demands, giving an added flexibility. The smaller shipyard cannot trade up. This is illustrated in Figure 5 which considers order density in the tanker market that is the ratio of the number of ships on order in a sector of the market to the number of shipyards participating in that sector. (These graphs are based on a sample of 1,407 tankers ordered or on order since 1989). Competition

reduces as the size of the ship increases. At the far end of the scale, i.e., VLCCs, the level of competition is much reduced, and a number of shipyards are currently anticipating the replacement of the VLCC fleet when prices could be good, due to the balance between supply and demand in this sector. Price per unit of work for a VLCC is currently around the same level as the handymax sector, but this may be adversely affected by new capacity due to come on stream in Germany, South Korea and China. This could upset the fine balance in this sector.

Thus, it can be seen from Figure 5 that, whilst market volumes are greatest in the smaller size, competitive conditions improve as size increases.

Initially the decision as to whether to relax an existing constraint in a shipyard is a fairly simple matter of economics, considering the cost and the perceived benefit. However, the cost is likely to be high, and ultimately the decision must be made on the perception of the risk associated with the expenditure, in addition to simple economic calculations.

Finally, there is a need to match the physical capacity of a shipyard with the level of Workforce.

Capacity is very difficult to specify in exact terms. It is a function of many parameters including surface area, cranes, equipment, launching arrangements and above all people. The most useful measure of capacity is output (measured by compensated gross tons) per manyear worked. For example, a shipyard of 1,000 persons, operating at a reasonably productive level of output of 50 CGT produced per manyear worked, would have a capacity of 50,000 CGT per year or around 3.5 handymax bulk earners. If the shipyard has restricted berth space (particularly if it is unable to build in tandem or semi-tandem), or perhaps even more critically if it has restricted berth cranes, then launching this many ships could be a problem. Conversely, 50,000 CGT equates to roughly one 125,000m<sup>3</sup> LNG carrier per year, the production of which may not be constrained by the launching bottleneck.

## MARKET VOLUME, MARKET SHARE AND OTHER MARKET FACTORS

It is not the intention to present here a specific market forecast. However, it is important to gauge the relative sizes of market sectors, to judge the size of the target that is being aimed at. This is illustrated in a nondimensional format in Table V.

TARGET MARKET VOLUMES	
Shp Type	Relative Market Volume
Bulk Carrier	62.1
General cargo	53.5
Tanker	31.5
Container	21.6
Passanger (including Ferries)	17.4
Chemical Tanker	17.1
RoRo	13.9
Reefer	12.8
OBO	
LPG	1.3
LNG	1.0

Table V

The statistics in this Table are based on a recent market forecast undertaken by the author for ships between 5,000 dwt and 100,000 dwt. The smallest market sector, LNG carriers has been assigned a factor of 1. The other sectors have been assigned a factor based on the relative size of the market. For example, for every 1 LNG ship constructed, 21.6 container ships will be constructed.

In terms of volume, the market can be divided into three sectors as shown in Table Vi.

Volume Markets :	
	Bulk Carrier General Cargo Tanker
Intermediate	Container Passenger Chemical Tanker RoRo Reefer
Niche	OBO LPG LNG

Table VI



The implications of these classifications in terms of market share are important. For the shipyard outlined above as capable of producing 50,000 CGT per annum, equating to 3.5 bulk carriers or one 125,000 m<sup>3</sup> LNG carrier, the implied levels of market share would be around 6% of the bulk Carrier market but well over 80% of the LNG market it follows from this that a shipyard with 2,000 workers aiming to specialize in the LNG sector would be short of work.

A strategy aiming at niche sectors has to be very carefully considered. The intermediate sector is also not without its problems. For example, 99 container ships were delivered in 1993, representing a peak of deliveries in this sector. The container ship market is forecast to improve, but not to a level significantly greater than the deliveries seen in 1993, although demand is likely to be steadier than seen in the 1980's and early 1990's. The caveat to this is that a new market entrant aiming a strategy in this sector is likely to have to gain market share at the expense of established specialist builders and competition Will be intense. Market entry will be difficult Conversely, in the volume sectors of the market market share can be gained through the significant market growth that is forecast giving a greater likelihood of successful market penetration.

Finally under this heading, the characteristics of likely orders should be considered.

In the volume sector, series orders or standard ships can be expected, low cycle times leading to high throughput This leads potentially to high economic efficiency in high cost countries, with overhead or establishment costs being recovered over high throughput, minimizing unit rests.

At the other end of the spectrum, in the niche sectors, orders are more likely to be for on-offs, with long cycle times and low throughput In some cases, an entire company overhead may have to be recovered against a single vessel, or even less than one vessel if the cycle time is greater than one year. This is considered further in the following section.

## **PRODUCTION CHARACTERISTICS AND ORGANIZATION**

Production characteristics vary significantly depending on the target market sector. This is best illustrated by considering two ships at the opposite ends of the spectrum a bulk carrier and a cruise ship. Various aspects of the production system are contrasted below for these two ship types.

### **Automation/Skill.**

High volumes and the high level of repetitive steelwork permits maximum use of automation in the construction of bulk carriers, requiring minimum craft skill levels. Conversely, passenger ship construction is difficult to automate and relies more heavily on craft skills.

### **Skill Balance,**

For the bulk carrier the emphasis is largely on steelwork with the reverse being the case for the passenger ship where outfit content predominates.

### **Throughput Characteristics.**

High volume flow throughput for bulk carriers permits the use of process orientated workflow. In the case of passenger ships, the long cycle time leads to a much more product orientated flow, with the ship being the primary workstation for much of the time.

### **Organization.**

Workstations remain largely fixed for much of the work involved in bulk carrier production with fixed operatives. Passenger vessel are better suited to multi-discipline teams working in ad hoc workstations and zones.

### **Overheads.**

The repetitive nature of series ship production enables overhead staff to be minimized in the case of bulk carrier production. This permits maximum economic efficiency, with low overheads recovered against high throughput. Conversely, higher numbers of planners, technical staff, QA and inspection staff, estimators, purchasers, supervisors and most

	<u>Tanker</u>		<u>Cruise Vessel</u>
<u>Attribute</u>			
Market Volume	High	← Increasing Volume	Low
Target Market Share	Low	Increasing Market Share →	High
Order Characteristics	series	← Increasing Order Length	Unique
Cycle Time	Short	Increasing Cycle Time →	Long
Automation Potential	Maximum	Increasing Skill Level →	Minimum
Skill Balance	Steel Trades	Increasing Outfit content →	Outfit Trades
Throughput	High Volume	← Increasing Throughput Volume	Low Volume
Overheads	Low	Increasing Overhead Costs →	Higher
Potential For High Economic Efficiency	High	Increasing Unit Cost →	Low
Production Organization	Defined Flow Lanes	← Increasing Fixed Workstations	Ship Orientated

Figure 6: Comparison of the Attributes of Volume and Niche Market Building

other overhead categories are required for passenger ship production.

The above factors are summarized, along with the market elements, in Figure 6. This figure demonstrates that production facilities must be matched to the target product mix. It would clearly not be efficient to construct a bulk carrier in a passenger ship facility, or vice versa, although technically it could be done. This is the reason why shipyards can no longer be all things to all shipowners, as they were 30 years ago, and that most successful shipyards today specialize in selected target areas. The target that most closely matches warship construction for those shipyards attempting to convert, is

cruise ship construction. It should be clear from the above that attempting to build volume ship types efficiently in a former warship shipyard is likely to be difficult without investment and possibly downsizing, in particular of overhead staff.

Mixing non-compatible ship types, such as bulk carriers and passenger ships, in the same facility should be technically and economically feasible, but would require very careful thought and planning. In particular, the allocation of overheads would have to be carefully considered so as not jeopardize the economic viability of the more simple ship types.

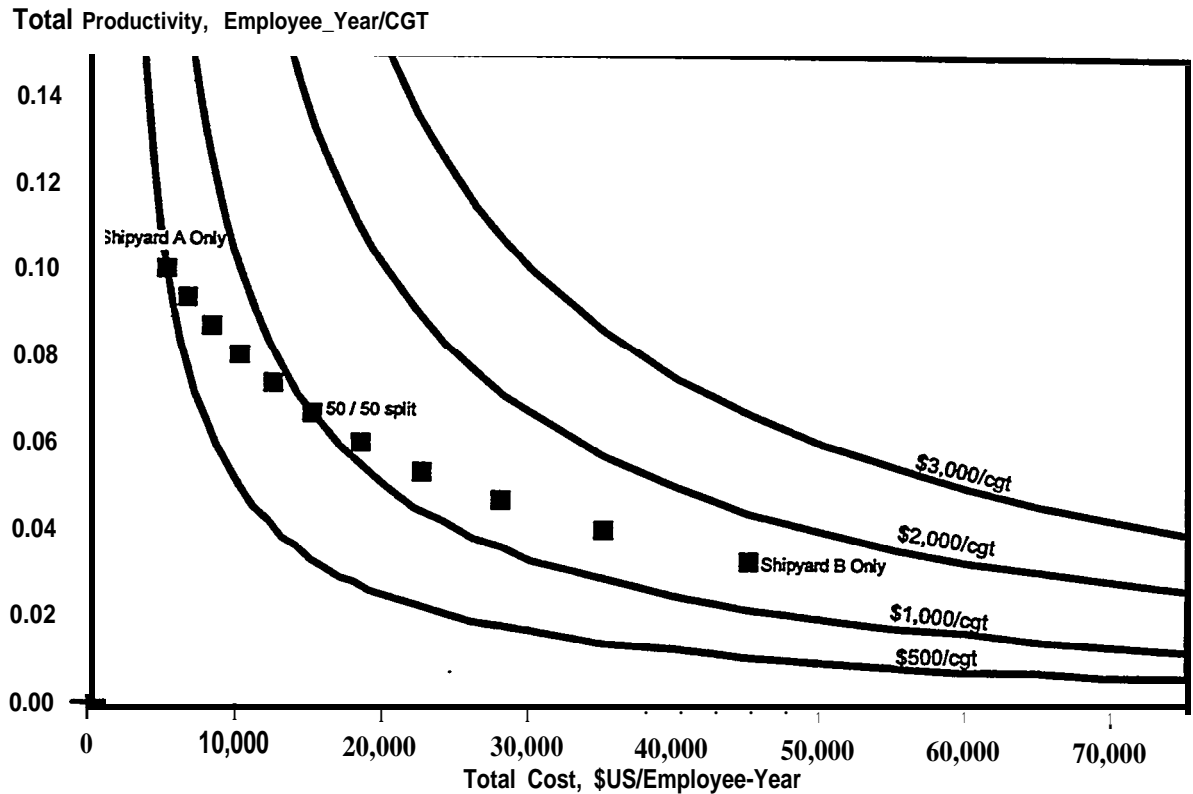


Figure 7: Combined Series Order Effect On Competitiveness

## OTHER STRATEGIES : ORDER SHARING

In addition to target marketing and the matching of facilities and organization to the chosen product mix, there are other options that could be utilized as part of an overall strategy.

As an example, the following calculations concern a strategy of combining a series order in two shipyards at different levels of competitiveness. The measure of competitiveness utilized is cost per unit of output the unit of output used being the Compensated Gross Ton.

Consider the case of a reasonably competitive shipyard in a high cost country, that proposes to form an association with a less efficient shipyard in a low cost country, with the aim of reducing unit costs of a series order built jointly in the two shipyards. This is illustrated in Figure 7.

Figure 7 is based on curves of constant cost per unit of output (Kattan and Clark 1993), taking into account total cost per employee (horizontal axis) and productivity (vertical axis) measured by employee years used per Compensated Gross Ton produced. Total cost includes labor costs and overhead costs, but excludes material costs and other contract costs such as builder's risk insurance or financing charges. The product of the two parameters gives a measure of competitiveness cost per CGT produced.

Shipyard A is typical of a developing country, with low productivity, but a very low operating cost, giving a level of competitiveness of \$500 per CGT.

Shipyard B is typical of an average level in Europe with a reasonable level of productivity but a fairly high cost giving a level of competitiveness of \$1,500 per CGT.

The components of these costs are presented in Table VII.

Shipyard A:	Productivity :	0.1" manyeera per CGT
	Cost per manyear	\$5,000
	Performance :	\$500 per CGT
shipyard B	Productivity :	0.033 manyears per CGT
	Cost per manyear	\$45,000
	Performance :	\$1,500 per CGT
* an output of 10 CGT per manyear worked		
* an output of 30 CGT 30 CGT per manyear worked		

Table VII

Share of Order (ShIPyard A : B)		combined cost per CGT	% Improvement unit Costa
A	B		
0	100	1,500	0
10	90	1,400	6.67
20	80	1,300	13.33
30	70	1,200	20
40	60	1,100	26.67
50	50	1,000	33.33
60	40	900	40
70	30	800	46.67
80	20	700	53.33
90	10	600	60
100	0	500	66.67

Table WI: Combined Series Order Effect on ComPetitiveness

Table VIII presents the combined level of competitiveness depending on the proportion of the order placed in either shipyard and the percentage reduction in cost per unit output from the situation in Shipyard B alone.

The validity of this strategy is clear from this Table. Significant reductions in cost per unit output are possible via this course of action, without any improvement in productivity in the higher cost shipyard. A 50:50 split of the order would lead to a reduction in unit costs of one-third.

The aim of presenting these calculations is to show, again, that strategy is not simply a matter of looking inwards to improve those factors under the control of the shipyard. As indicated in the introduction to this paper, external factors outside the control of the shipyard produce both opportunities and threats, and creative ways must be sought to maximize the advantage from the former, and minimize the

problems from the latter. Order sharing is one example of a possible strategy to do this.

## CONCLUSIONS

Shipyards do not operate in isolation. They are subject to forces imposed by the external environment to which they must react The external environment provides both opportunities and threats, and the nature of the external environment must be understood to enable these to be identified and addressed.

In general, external forces are outside the control of a shipyard. In particular this comment is directed at price, which fluctuates on a commodity basis. It is one of the characteristics of the shipbuilding industry, that very large fluctuations in price have been experienced in the past and it is largely due to this variation that shipbuilding is seen as a difficult and high risk industry.

In order to survive in this difficult environment a shipyard must adopt a inherent strategy to match the facilities and organization to a tartgeted market sector. This strategy must be considered very carefully, with decisions made on a rational and scientific basis, and not on intuition.

When deriving a strategy, the follow-rig factors must be considered:

- Physical constraints : There will be a maximum size of vessel that can be constructed and a limit to capacity, although both these constraints can normally be relaxed if this is justified;
- Market factors : the capacity of a shipyard can be related to market volume for specific target sector, and the market share required to achieve reasonable throughput can be identified. These must be reviewed along with the competitive situation to identify the potential for market sector penetration; and
- Production characteristics and organization: The characteristics of a shipyard must be matched to the chosen target market sectors. At different ends of a spectrum the

characteristics are highly automated, high throughput and low overhead to higher craft skill level, low throughput and high overhead.

Finally, an example is presented of a potential strategy based on sharing orders between shipyards at different productivity levels. The aim to this strategy is to reduce unit costs without changing the internal characteristics of either shipyard.

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# Increasing U.S. Shipbuilding Profitability and Competitiveness

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## ABSTRACT

The declining number of Government contracts for ship repair and new construction work, and the acknowledged competitiveness "Gap" has resulted in the need for U.S. shipyards to face the major challenge of reducing total ship cost, construction time and their general overall approach to meet the "necessary conditions" of commercial ship owners in order to obtain contracts. Increased profitability is also a necessary condition for short term survival but does not ensure that these shipyards will be competitive in the commercial ship world marketplace.

The significant impact on profitability and competitiveness resulting from reduction in construction time will be discussed. Construction time is defined as the time between contract award and delivery. The techniques that can be used to determine: What to change, What to change to, and How to cause the change will be described along with the paradigms that are present which greatly hamper the breaking of physical, policy and behavior constraints.

## SITUATION

Well over 90% of all new construction and major conversion work of ocean going ships in the U.S. is presently being performed by five major shipyards for one customer, the U.S. Navy. All of this work must be accomplished to meet Government type

contract requirements. The challenge facing U.S. shipyards is to become more competitive in the market. U.S. shipyards can increase their profitability considerably and still not be competitive in the market.

Although all five shipyards have considerable backlogs and, when options and/or projections are included, this Navy work extends out into late 1997 and beyond. Anderson and Svedrup, 1993 in their discussion responded as follows to this author's question why the U.S. shipyards are not competitive: What lies implicit is that U.S. shipbuilding must be "determined!" to change in order to increase productivity which we consider to be THE problem for U.S. shipbuilders.

Anderson and Svedrup, also discussed two other very pertinent statements relative to U.S. shipyard's becoming competitive: (1) Specialize, do not have a "Dual-Use" shipyard, and (2) Shipbuilding must be viewed in the long term. U.S. shipyards with long term Navy work must deal with the dual-use problem and it is believed that all have committed to the long term view. There are many other areas that are not within the control of U.S. shipyards that have a significant impact on profitability, and more so on competitiveness, because they affect not only the shipyards, but have a greater effect on ship owners. Some of these areas are: foreign shipbuilding subsidies, International laws and regulations. depreciation laws, special financial agreements. and ship operational costs.

### How Wide Is The Competitive Gap?

One of the major tasks U.S. shipyards face is trying to determine how big is this competitiveness "Gap." U.S. shipyards have not built commercial ships that can be used in any comparison in a long time.

Table I provides a 1993 evaluation of three other shipbuilding regions to the U.S. in eight major functional areas. The largest gaps are in the Marketing function followed

by the Overall function and the Strategy Management which appears in two of the three range comparisons. These comparisons seem to validate that management paradigms are the core problems that must be addressed before the issues of increasing profitability and reducing the competitiveness gap can be effectively resolved.

A comparison of scheduled construction time for a U.S. shipyard and Japanese shipyards is shown in Table II.

SHIPBUILDING REGION	OVERALL	HUMAN RESOURCES	STRATEGY MANAGEMENT	TECHNICAL
EUROPEAN COMMUNITY,	85-115	90-115	75-130	95-110
JAPAN, RANGE	95-120	100-125	95-125	90-110
KOREA, RANGE	90-110	100-120	85-110	85-105
USA, RANGE	<u>65-90</u>	80-105	70-90	70-100
RANGE of GAPS *	20/30/55	10/20/45	5/40/60	15/10/40
	MARKETING	PRODUCTION	PURCHASING	PLANNING
EUROPEAN COMMUNITY	85-120	90-110	85-115	85-115
JAPAN	100-115	90-110	90-125	100-125
KOREA	110-130	90-115	80-95	80-95
USA	40-60	75-95	75-95	80-100
RANGE of GAPS *	45/70/90	15/20/40	5/30/50	0/25/45

\*GAPS = Range of USA to other Regions: Low:Low/High:High/Low:High.

Underlines indicate lowest and highest in each functional category.

Table I Competitive Evaluations of Shipbuilding Regions  
Index of Commercial Shipbuilding Competitiveness by Function  
(100 = Average International Shipyard)

Source: Bunch, 1993.

Shipyard	USA	USA*	Japan	IHI	AJI	MHI	SHI	VLCC
CA to SC	61	39	22	34	34**	26	26	43
SC to D	79	79	38	43	39	39	39	47
CA to D	140	118	60	77	73	65	65	90

\* Based on Japanese Material lead times. \*\* 50% before Contract Award.

IHI = Ishikawajima Harima Heavy Industries.

AJI = Advanced Jointless Information Systems by Assimilation and Inheritance

MHI = Mitsubishi Heavy Industries, 80,000 TWDT Double Bottom Product Carrier

SHI = Sumitomo Heavy Industries, 85,000 TWDT Bulk Carrier.

VLCC = Very Large Crude Carrier.

CA = Contract Award, SC = Start of Construction, D = Delivery.

Table 11 Construction Time (in weeks) Comparisons

Source: Bunch, 1987, Bennett and Lamb, 1994.

Although the above figures represent several different types of ships, the one U.S. shipyard requires an average of 29, 37, and 66 more weeks for the CA to SC period, SC to D period and the CA to D period respectively: around double the time.. Table 11 indicates that almost 50% of the total gap results from actions taken during the period from CA to the SC and that more than 50% of the total gap takes place from SC to D.

Actions taken during this first period will have a significant impact on construction time because these actions provide the prerequisite information needed to accomplish the multitude of construction tasks.

The reported difference (1980) between a U.S. shipyard building a similar ship in the SC to Launch period, i.e., fabrication, assembly and erection activities is 2.4, 2.6 and 2.5 times that of a Japanese yard respectively (Bunch, 1987).

Some one berth or single dock Japanese shipyards can complete five or six ships in a year; and with four month erection times, this means there must be berth or dock times overlapping (Bennett and Lamb, 1994).

All tasks performed in the construction of a ship are in accordance with the shipyard's management systems (set of formal and informal rules). These rules are in effect many paradigms. Apparently following these paradigms has resulted in no significant reductions in U.S. shipyard construction times.

"...no U.S. shipyard, has to the best of our knowledge, offered the Navy alternative approach, benchmarked against its foreign competition, that would satisfy the Navy that their particular build strategy was indicative of world class standards." (Spicknall and Wade, 1993).

The Navy also has paradigms which may not be congruent with the U.S. commercial shipbuilding needs relative to ship construction times.

Another significant gap area

between U.S and foreign competition is in construction manhours. A comparison of the manhours required to build similar ships in a U.S shipyard and a Japanese shipyard indicated the Japanese shipyard required 39% of the effort of the U.S. yard (Bunch, 1987). Presently, the gap although significant is not as great as estimated in 1987 (Bunch, 1987, Storch and Clark, 1994).

The present administration, concerned about the ability of U.S shipyards to make the transition into the global commercial shipbuilding market have initiated a program to help narrow the gap. The five main elements of their program (Beargie, 1993) are:

1. Title XI Loan Guarantees.
2. Research and Development administered under the Department of Defense organization called MARITECH,
3. Elimination of unnecessary government regulations which impose burdens on the shipbuilding industry,
4. New market promotion program to help U.S. shipyards identify and win potential foreign orders (one objective will be the facilitation of cooperative agreements between U.S. and foreign shipyards), and
5. Continuing efforts to end foreign ship building subsidies.

The Advanced Research Project Agency (ARPA) is managing the Maritech program and has already awarded numerous cost-sharing contracts totaling many millions.

Under the new Title XI program, ship owners (foreign (except for U.S. flag ships) and domestic) can obtain 25-year financing for up to 87.5% of the actual cost of constructing a ship for export-at a fixed interest rate. Some Title XI monies also are for U.S. shipyard modernization.

Increasing foreign labor costs and positive exchange rates may also help to narrow the gap. However, the challenge to reduce the competitive gap and leapfrog the competition must be the major goal of U.S. shipbuilders.



WHAT ( PARADIGMS) TO CHANGE? AND  
WHAT ( PARADIGMS) TO CHANGE TO?

U.S. shipbuilders are in need of a transformation from the way that they have been doing business in the past. To paraphrase Barker ( 1992), shipbuilding is a business that has many paradigms: management, material, marketing, engineering, planning and scheduling, accounting and many others. In addition there are even more paradigms in the cultural behavior of the shipyard's management, workers, vendors, etc., not to mention the primary customer's (U.S. Navy) numerous paradigms.

The interrelationship of all these paradigms is crucial to the success and longevity of any U.S. shipyard. "A paradigm, in a sense, tells you that there is a game, what the game is, and how to play it successfully...A paradigm tells you how to play the game according to the rules...A paradigm shift, then, is a change to a new set of rules to be used in the game." (Barker, 1992)

The idea of a game is a very appropriate metaphor for paradigms because it reflects the need for borders and directions on how to perform correctly.

The highly interdependent structure of the "forest" of paradigms that are integral with shipbuilding, coupled with the condition that there has essentially been only one "customer" for a long period of time, has resulted in only one set of rules for "playing the game."

To meet the present necessary conditions in the market, numerous paradigm shifts (transformations) will be required because the rules of this "new game" are quite different.

The two basic levels of the Transformation Process by which a company reconceptualizes and redesigns itself (system) to remain competitive are (Swartz, 1994):

1. A systematic approach to Continuous Linear Improvement and

2. a systematic approach to Continuous Non-Linear Improvement redesign of the system.

Continuous Improvement is usually linear and consists of reduction of valueless time, activity, and variance. System redesign is usually non-linear and involves: new process intent, new process models, new learning and improvement system, and new value-adding technology. Reward systems are a necessary condition of any learning and improvement system. Learning is defined as - new concepts and new ideas entering your brain. Improvement is the process by which one learns to change:

1. What one does,
2. What others do, or
3. The system that affects peoples lives.

The major transformation for U.S. shipbuilders is how to make the necessary changes to "leapfrog" the competition. Benchmarking can provide insight as to what the competition is doing, but world class competitors are not waiting for the U.S. shipyards to catch up and as time moves on, the "Gap" actually increases as shown in Figure 1.

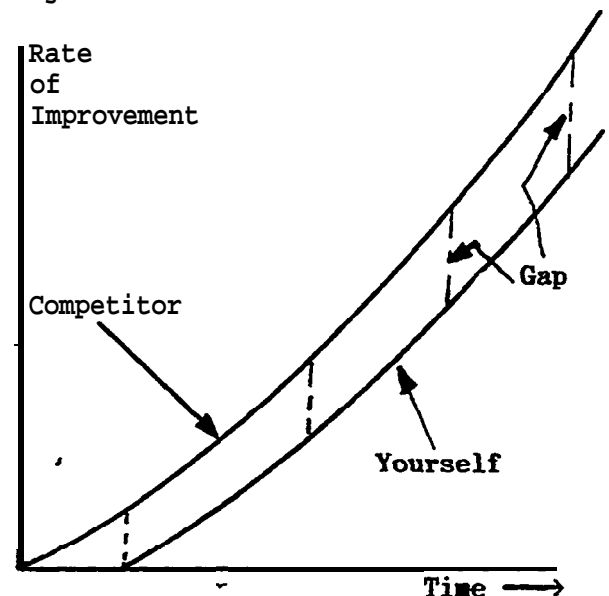


Figure 1., Rate of Improvement

Source: (Goldratt and Fox, 1986)

A good starting point to look for paradigms-that are hampering U.S. shipyards from being competitive was paraphrased by Walton in 1986: Deming explained that workers' performance is determined solely by the system in which they are working. Management, he said, must not only recognize that most of the failure for a system to produce the desired results is due to the system itself, but that management must change itself, and the system, to improve outcomes.

Deming identifies two major paradigms in the above statement, the "system" and that management must change itself (its thinking) before it can change the system. The system that U.S. shipyards are using is based on years of trial and error and experience to meet customer requirements. With the demise of commercial shipbuilding in the U.S. the system that has been developed to meet one customer's requirements is in itself a major paradigm, but not the core problem.

#### The Key Paradigm - Thinking

After the second World War, analysis became the dominant mode of thought, so much so that even today analysis and thinking are used as synonymous terms. The following definitions provide a clear distinction between two thinking approaches. The analytical approach utilizes the following three steps (SBM, 1993 ):

1. Reducing the problem to a set of solvable problems,
2. Solving the component problems, and then
3. Assembling them into a solution as a whole.

The systems approach is an alternative to the analytical approach. A system is a collection of parts which must satisfy the following three conditions. First, the performance of the system as a whole is affected by every one of its parts. Second, the way that any part affects

the whole depends upon what at least one other part is doing. The third condition is that if one takes any number of parts and groups them in any way, they form sub-groups which will be subject to the same first and second conditions as the original parts are.

Two principles of systems thinking follow (SBM, 1993).

1. If one takes a system apart to identify its components, and then operates those components in such a way that every component behaves as well as it can, the system as a whole will not behave as well as it can.

2. If a system is behaving as well as it can, none of its parts will be.

#### The Key Paradigm Shift

Traditionally, successful managers have strong problem-solving skills. When a real problem occurs, they solve it. This is how most managers are evaluated as to their effectiveness on the job. Most shipyard managers are paid to solve problems whether they are trivial or complex, so naturally managers spend most of their time doing just that.

Barker, 1992 describes this condition as a "great big buzzing confusion." This condition is also commonly called a "Mess." What reality consists of are messes, not problems. A mess is a system of "perceived problems" or "symptoms" of the underlying cause that drives the system. The traditional way of managing is to treat the mess analytically, but if a true belief that the systems approach does exist, then an analytical approach can not provide a solution to the mess; only a situation referred to as "fire-fighting" can solve the mess.

One of the most important management skills during times of high turbulence is anticipation (Drucker, 1980). There it is suggested that managers improve their skills so that their actions are mostly in the upper

right quadrant shown in Figure 2. The area bounded by the oval ("A") is the area between anticipation, problem avoidance and opportunity identification where managers should strive to operate. The lower left quadrant where most of oval ("R") is located is the area between problem solving and reaction where most managers now operate. It is in the opposite area ("A") that the greatest leverage over the future can be realized - personally, organizationally, and nationally.

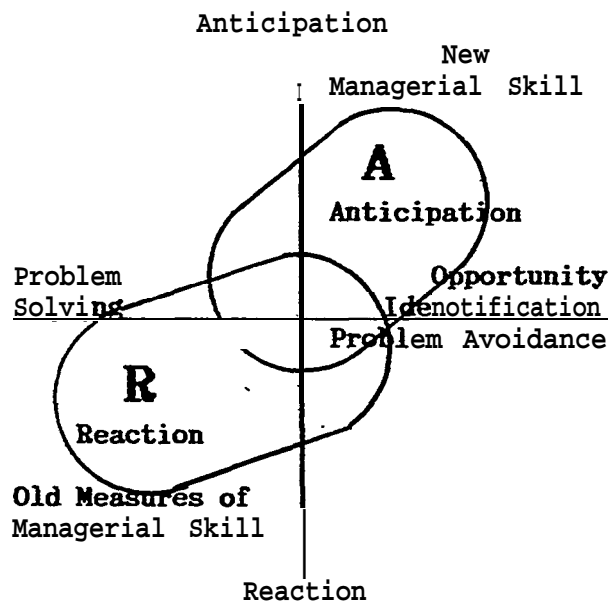


Figure 2. New Measures of Management Skill

Source: Barker, 1992

The time between changes is decreasing and the magnitude of change is increasing. Organizations and people must move from the old style of solving problems (firefighting) to a new style of anticipating potential problems before they happen and try to keep them from occurring in the first place. Peoples' and organizations' attentions must shift from looking for the fire-fighting type of solutions to developing processes which will assure the maintenance or improvement of solutions over time.

The competitiveness gap facing U.S. shipyards indicates that initial efforts should be in the area of system redesign. A prerequisite to system redesign will be the implementation of systems thinking by management. Management must change itself, and the system, before the key paradigm shift can result.

#### Primary Focus - Another Key Paradigm

Unfortunately, organizations and people live in an impatient world that confuses fire-fighting reaction type actions as progress. Most organizations have invested and continue to invest millions in improvement programs under many banners such as Manufacturing Resources Planning (MRP II), Total Quality Management (TQM), Just-In-Time (JIT), Theory of Constraints (TOC), and other such programs. Each one of these programs in isolation appears sensible, and many have resulted in initial impressive improvements as Curve A in Figure 3 indicates. However, experience has shown that the slope of Curve A (the rate of sustained improvement) does not continue. This rate of improvement flattens out over time, then is stagnant and in some cases declines to the point of bankruptcy!

Until a proposed action plan is rigorously checked out to make sure that it has a high degree of assurance that it will lead to the long term desired effects (goals), then the application of time, resources, and capital will usually result in a process of on going linear improvement and Curve A type results.

It is this lack of primary focus on what drives a system that leads managers to do the wrong thing. If organizations and people do not take the time to clarify what they want - by trying to understand all the possible ramifications of their proposed programs - their actions can not be strategically congruent.

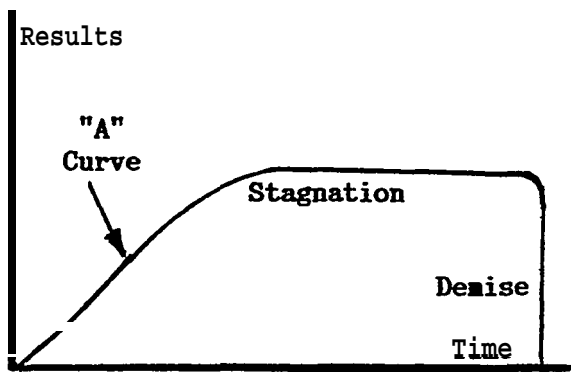


Figure 3. Rate of Improvement

Source: Goldratt, 1990

U.S. shipyards, like other for profit businesses, have been traditionally organized along functional lines which include sales, production, engineering, materials, finance, human resources, and so on. Each of these functions are usually broken down into smaller functional groups (departments), which in turn are further subdivided into levels such as managers, superintendents, supervisors and in some cases leadmen. If, as traditionally done, each of these levels and each of these functions perform as efficiently as they can, then according to the systems approach described above, the shipyard will not be efficient!

One has only to look at the history of U.S. shipbuilding to confirm that paradigms have been developed that conform to the analytical approach. Government contract requirements which require performance measuring of individual work order budgets and schedules reinforces the analytical approach.

The current goal of U.S. shipyards' is fairly clear: To become more profitable and competitive in the world market. In order to achieve this purpose, the synchronized effort of many resources is needed. The fundamental principle of the Theory of Constraints (TOC) is: The organization should be viewed as a chain composed out of many links.

The contribution of any link is strongly dependent upon the performance of other links - A chain is only as strong as its weakest link.

Very few organizations operate as a chain (all dependent operations in series), most operate as a grid of chains. Thus the number of weakest links (constraints) that determine the performance of an organization, depends on the number of independent chains comprising the grid. The more complex the organization (like a shipyard), the fewer the number of independent chains it contains; more complex means more dependencies. Thus, if an organization wants to improve its performance, the first step must be to IDENTIFY the systems constraint (Goldratt, 1990).

The traditional shipyard practice of trying to improve the budget and or schedule performance of any one of the thousands of work orders (links) required to build a ship is contrary to the above TOC principle. The bottom line impact resulting from solving independent (links) problems is usually very small.

To get out of the "mess", logic must be used. Not the correlation techniques used in the soft sciences and predominantly by managers today, but the logic of Effect-Cause-Effect (ECE) used in the hard sciences to answer why things are related. When this paradigm shift from using correlation techniques to using ECE techniques is made, then the problem solving process can be better relied upon in the search for good iterative solutions and in preparing practical strategic plans.

These same ECE techniques along with a procedure called: Categories of Legitimate Reservations (CLRs), are used to specifically build and check the accuracy, logic, and existence of all causes, effects and relationships. This challenging of all logic is integral to the TOC, Thinking Processes (TPs), and the applications derived from their use.

These TPs are applicable to all types of organizations. The TOC TPs empower managers with tools to systematically, logically, and effectively answer three fundamental questions:

1. What to change,
2. What to change to, and
3. How to cause the change.

The TOC TPs also provide the logical techniques to not only answer: Why is the system sick, but also *two* other major questions: What changes are required to the system, and most importantly: What actions does management have to take to effectively implement the cure?

Elmes, (1992) concludes that: "most of the procedures used in TP, have a solid scientific basis... Furthermore, it is now possible to document the techniques. ..because it contains some unique feature (the effect-cause-effect and evaporating cloud techniques), and because the entire package of techniques is aimed at improving organizational problem solving."

#### Other Major Paradigms

One only has to look at how most organizations, people, and as the best example, the Government act relative to problem solving to confirm the following statement: The tendency is to look for the easy way out by circumventing the requirements instead of exposing the hidden assumptions.

Complexity in problem solving results when compromises are developed to satisfy more and more requirements. In reality, what has been developed are actually tolerable compromises. Tolerable compromises are generally a result of some policy that management has established and implemented at some time in the past to solve a problem existing at that time. The assumptions made at that time, upon which these managerial decisions or policies were based were sound, but have rarely been challenged. The results are that many of these

policies have become constraints.

Many managerial decisions and long established policies also adversely affect the throughput of a manufacturing company. These types of constraints are difficult to identify and much harder to change due to the tremendous amount of Inertia that has been built up over many years because the organization becomes comfortable with the status quo. These types of management decisions and policies can magnify problems created by other systems or they can encourage decisions that lead to global suboptimization of the "present operational "System" of the organization.

For example, the use of Economical Order Quantity (EOQ) or Economical Batch Size (EBS) techniques have been used in production and purchasing as a standard policy in many U.S. companies. Setting batch sizes based on EOQ or EBS is still a common practice (policy) in many manufacturing plants around the world, except for those implementing JIT technology. JIT challenged the traditional assumptions upon which Figure 4 is based relative to setup costs and proved that the reduction of inventory was a major driver to increased throughput and profitability.

By implementing new innovative techniques the Japanese reduced setup costs significantly and they reduced the size of transfer batches which enabled them to start the next operations much earlier. The role of reduced inventory was one of the major reasons Japan was able to leapfrog competing nations in manufacturing areas as this paradigm shift (policy) improved products in the quality and engineering areas, resulted in higher margins and lower investment per unit in the price area, and improved responsiveness by creating shorter quoted lead time and better due date performance. (Goldratt, 1986)

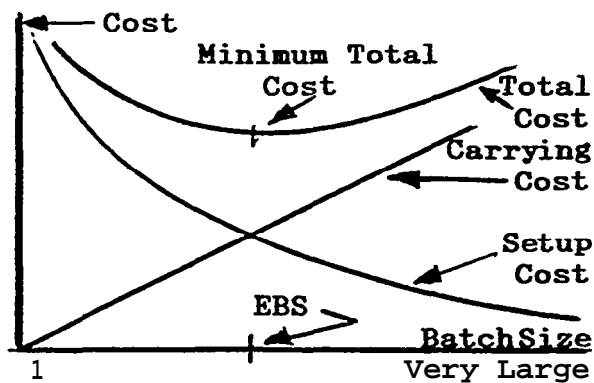


Figure 4 Total Cost Curve for EOQ Batch-Sizing Approach

Source: Umble and Srikanth, 1990

The Japanese consider inventory a liability. However, on their financial balance sheets, inventory is listed as an asset. Generally Accepted Accounting Practices (GAAP) also list inventory as an asset. This apparent conflict can be resolved by using the TOG Evaporating Cloud (EC) technique. A win-win solution results: Inventory is only an Asset when it protects Throughput (Rack, 1992).

The EC technique is one of the processes used in the TOC TPs and is based on the following three steps:

Step 1. Present the problem in a diagram format.

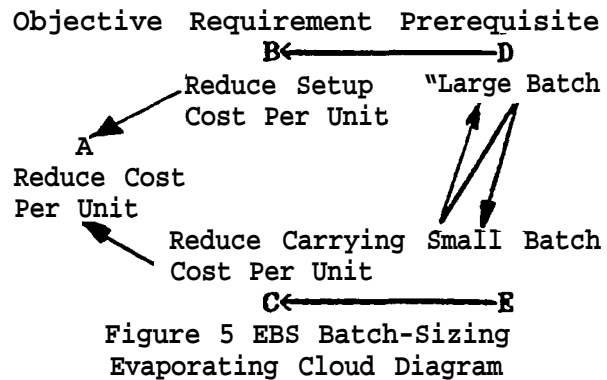
Step 2. Expose and verbalize the assumptions behind the various arrows.

Step 3. Challenge the assumptions to the point that one or more is exposed as invalid or irrelevant.

The conflict shown in Figure 5; large batches v. small batches) is essentially resolved (evaporates) because the correct course of action (valid assumptions) is evident.

The EOQ or EBS EC diagram would look like Figure 5. The Objective, Requirements, and the Prerequisites are known and the Conflict is - large batch or small batch.

The traditional solution was to relax the requirements by making a



Source: Goldratt, 1990

compromise by establishing an EOQ or EBS. The EOQ or EBS concept is not a win-win solution. The JIT solution was based on correlations and appeared to be a satisfactory solution-reduce setup costs and transfer batch sizes. The TOCTP techniques are based on ECE which rely more on a process rather than just good intuition to guide users in search of a good iterative solution and strategic plans. Using the TOG TP techniques, the assumptions and the challenges of these assumptions reveals a more powerful solution. Table III, lists the assumptions behind the arrows and the reasons why these assumptions are invalid or irrelevant, (erroneous).

The apparent win-win solution relative to the Figure 5 objective is that large production (setup) batches are required for cost effective constrained resource operations and that small transfer (inventory) batches should also lead to cost effective operations. A traditional EOQ or EBS tolerable compromise and the improved solution offered by JIT methods can be replaced by use of the TOG EC techniques and result in improved (second order) solutions.

The JIT approach does not recognize the inherent differences in resource types (constrained and non-constrained). In reality, inventory is required to maintain present throughput and to protect future throughput.

The conflict as to inventory being a liability. or an asset is therefore not resolved. The TOC EC technique resolves this conflict.

Table III EC Assumptions and Reason Assumption is Erroneous

EC Assumptions	
<b>B←D</b>	There is no distinction between the value of setup time at a bottleneck versus a non-bottleneck.
<b>C←E</b>	The carrying cost are the only the dollar cost to actually carry the inventory.
<b>D↔E</b>	There is only one aspect of hatch size to consider. "A Batch is a Batch."

#### Reason Assumption is Erroneous

<b>B←D</b>	Distinction is that savings in setup time usually results in more idle time on non-bottlenecks.
<b>C←E</b>	There are numerous additional costs associated with carrying inventory such as handling, records etc.
<b>D↔E</b>	Setup is a production process and constraints require large batches to minimize loss of throughput. Moving inventory is a transfer operation and small transfer batches should improve throughput. There are two types of batches (process and transfer) to be considered

#### Logistic Paradigms

Most logistic paradigms result inherent constraints in the production Planning and Control (PPC) system in use by most if not all U.S. shipyards. Logistic constraints are often difficult to identify and/or change. Statistical fluctuations and the numerous dependent resources are integral in the construction of a ship and usually result in a significant negative impact on the throughput of the system and more importantly, the

shipyard's bottom line.

Logistical constraints are internal constraints (within the control of the shipyard). To break these types of internal constraints usually requires a drastic change to existing PPC systems that have been in place for many years.

Scheduling of a shipbuilding manufacturing environment is basically a combination of Project Management systems and PPC systems. A shipyard's PPC system is a combination of Continuous Production systems (fabrication and assembly line manufacturing), like a general job shop, and Intermittent Production systems, characterized by batch production. These two systems in turn use different systems for more detail scheduling. Continuous Production systems use Flow Control systems while Intermittent Production system use Order Control systems which are generally more complex.

Program Management systems currently use two techniques for establishing overall planning and scheduling parameters, the Project Evaluation and Review Technique (PERT) and the Critical Path Method (CPM). PERT and CPM assume that unlimited resources are available for project activities.

Simulation, as well as other research, investigating traditional PERT and CPM assumptions, has demonstrated that current PERT/CPM based scheduling techniques generate critical path estimates that consistently underestimate project duration. While PERT techniques do recognize activity variability, they do not recognize the fact that critical chain path interactions can delay project completion. Many of the assumptions required to deal with Resource Constraint Project Scheduling problems can be relaxed through the use of simulation which, unfortunately can lead to tolerable compromises.

Figure 6 depicts the shipbuilding scheduling problem in EC format.

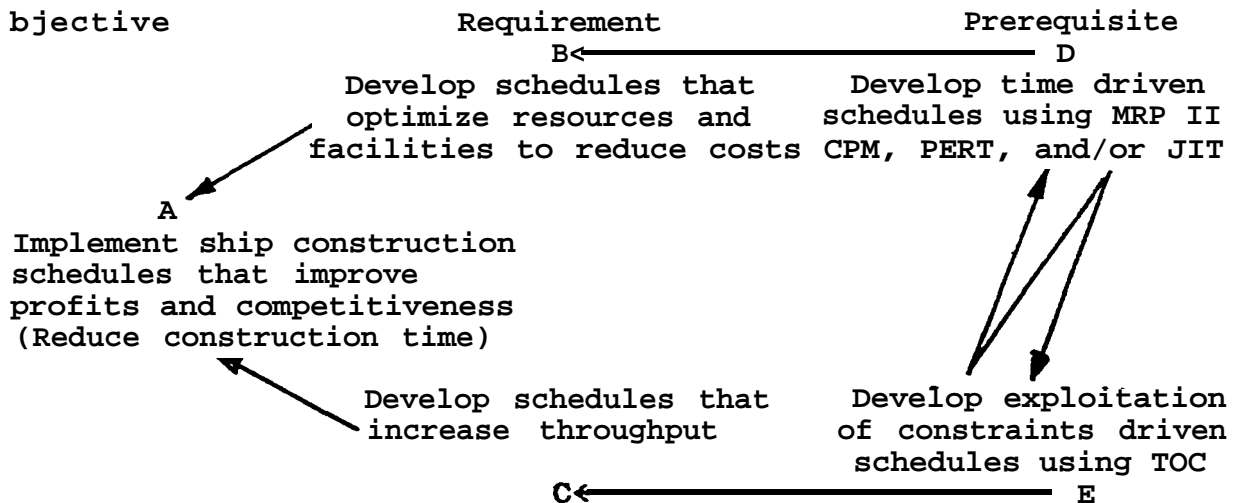


Figure 6 Shipbuilding Scheduling  
Evaporating Cloud Diagram

Table IV below, lists the assumptions behind the arrows and the reasons why these assumptions are invalid or irrelevant (erroneous).

#### EC Assumptions

- A←B** Schedules that optimize resources and facilities will reduce costs and result in improved profits.
- B←D** Time driven schedules produced by traditional systems will result in optimized resources and facilities.
- D↔E** Time driven traditional scheduling will meet objective.

#### Reason Assumption is Erroneous

- A←B** The optimization of any resource except the constraint-usually does not reduce cost.
- B←D** The optimization of non-constraint resources will increase inventory and increase costs.
- D↔E** Time driven schedules increase ship construction time and costs.

Table IV EC Assumptions and Reason  
Assumption is Erroneous

Traditional methods of scheduling shipbuilding work use time as the driver. Over the years more and more time has been inserted in these schedules to act as buffers. The real effect of these buffers result in an extension of the scheduled construction time. Goldratt, 1990, provides a detailed discussion of traditional scheduling methods. Using the "exploitation of the constraints" as the "Driver" produces physical constraint free schedules that are realistic and immune to a reasonable level of disruption. Candidate realistic schedules should be judged against the fundamental TOC measures: Throughput (T), Inventory (I), and Operating Expense (OE) which are defined later.

Realistic schedules are resource feasible schedules. There is no conflict between the system's constraints and there is no resource contention which occurs anytime that an activity or operation must be delayed due to lack of resources. Immune schedules are not affected by statistical fluctuations and dependent events.

It is important to distinguish Operations Scheduling (OS) from Master Production Scheduling (MPS).



MPS determines the kinds of products and the quantities to be produced in some future period. OS is at the lowest level of the planning hierarchy and requires a greater amount of detail. The TOC scheduling technique combines MPS and OS in away that causes them to be less discernable as separate entities than traditional methods. In this light, MPS is not ignored and the traditional OS problems are incorporated into the focus of the management environment comparisons that must be made by management.

Umble and Srikanth, 1990, discuss the following principle: Make sure the critical resources are working on the right activities at the right time. This requires the identification of Critical Capacity Resources (CCRs), defined as: Any resource which, if not scheduled and managed, is likely to cause the actual flow (critical chain) of product through a plant to deviate from planned flow. When identified, they become the focus point for management's attention as they have a significant impact on the throughput of a shipyard.

If CCRS exist, every spare minute that could be "squeezed out" of the available time on these CCRS should be utilized. Table V provides a Schedule/Time Analysis based on the time available per week.

1 Shift	Scheduled	Non-Scheduled
5 of 7 days	23.3%	76.2%
7 of 7 days	33.3%	66.7%
2nd Shift		
5 of 7 days	47.6%	52.4%
7 of 7 days	66.7%	33.3%
3rd shift		
5 of 7 days	67.0%	33.0%
7 of 7 days	93.3%	6.7%
* 5 of 7 days	71.4%	28.6%

\* Production operations continue through lunch periods either by working overtime, assigning extra teams, or by other means.

Table V Schedule/Time- Analysis

The percentages listed represent the productive scheduled time and the protective non-scheduled time on 1, 2, or 3 shifts and for 5 of 7 days and 7 of 7 days. Also shown is the added capacity gained by working through lunch hours. U.S. shipyards usually work a full 1st shift and a partial 2nd shift. Table V indicates that the 3 shifts 5 days a week schedule results in 33% additional available time and the 2 shifts, 5 days a week schedule has more time available than scheduled time {52.4% v. 47.6%}.

"An hour lost at a bottleneck is an hour lost for the total system" (Goldratt, 1984). Therefore an additional non-scheduled hour worked on a bottleneck is equivalent to an hour worked by the total system. The resulting positive impact on a shipyard's profit would be significant.

#### Cost Accounting Paradigms

The fundamental problem with Generally Accepted Accounting Practices (GAAP) is that they can not correctly measure the impact of local decisions and actions on the bottom line. Another basic problem, confirmed by GAAP experts, is that many of the original assumptions upon which these practices are based, are no longer valid.

McFarland, 1966, discussed the following key points in his study of management accounting concepts:

1. The presence of capacity constraints is a distinguishing characteristic of short run planning.

2. Identification of the constraints of a system is a prerequisite for distinguishing relevant costs.

3. Maximize contribution margin in terms of constraint resources.

4. Interdependence of the entities need to be considered in product and market segmentation decisions.

Many cost and management accounting textbooks and courses have

reinforced the erroneous impression of analytical independence. Managerial accounting is highlighted as focusing on parts or segments of an organization.

TOC has enhanced our understanding of constraints in at least three important ways:

1. Recognition that every system is constrained,
  2. The important role of non-constraints relative to exploitation of the constraint decisions, and
  3. The recognition that the constraint(s) of a system need not be physical in character.
- Policy and cultural behavior type constraints are very important considerations.

These three observations have immense implications in the practice of management accounting. The primary reason that cost accounting practices are so hard to break is that these practices (paradigms) have been the way that people have been educated, businesses have been operated, and financial and performance measurements have been calculated and evaluated for many years. Management and business schools are still teaching many of these obsolete subjects. This has resulted in many organizations and people having huge amounts of INERTIA.

The TOC EC technique can be used to resolve the conflict as to what cost accounting method (GAAP v. TOC) should be used to measure the results of shipyard improvement programs. By challenging the assumptions (Table VI) behind the logic (arrows) in Figure 7 a clear course of action is revealed.

GAAP results in an accurate determination of overall (global) company financial conditions except for the previous identified conflict on Inventory measurements.

The GAAP and TOC formulas will provide similar global measurements except in the conflict area. These global financial measurements are good for developing strong paradigms for judging the "System" but are very limited in judging the impact of local actions on the goal relative to:

1. Buying new equipment,
2. Investing in quality,
3. Product pricing, and
4. Workcenter performance, etc.

These cost Accounting and conventional reporting systems paradigms result in using the cost figures produced by the "system" that emphasize cost control first, then throughput and then inventory. Both operating expense and inventory have absolute limits, they can not be reduced below zero.

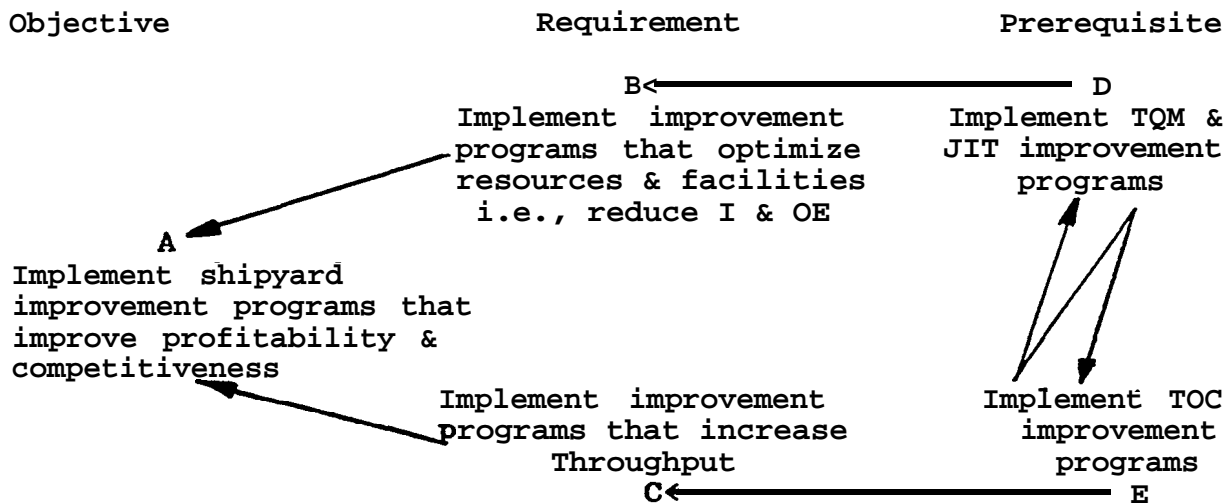


Figure 7 Improvement Programs Evaporating Cloud Diagram

## EC Assumptions

- A←B Optimization of resources & facilities improve profits & competitiveness.**
- B<-D TQM & JIT programs will reduce Inventory and Operating Expense costs .
- D<->E TQM & JIT programs that optimize resources and facilities improve profits and competitiveness.

### Reason Assumption is Erroneous

- A<-B Optimized resources & facilities have little impact on profits & competitiveness.
- B<-D TQM & JIT programs do not address constraints only inventory and Operating Expense reductions.
- D<->E Increasing Throughput, not reducing Inventory and Operating Expense costs, will have biggest impact on profits and competitiveness.

Table VI EC Assumptions and Reason Assumption is Erroneous

The TOC formulas listed below offer an alternative to GAAP. All four formulas include at least two of the three following TOC definitions.

Throughput (T): All the money the system generates through sales.

Inventory (I): All the money the system invests in purchasing things the system intends to sell.

Operating Expense (OE): All the money the system spends in turning Inventory into Throughput.

The conversion of T, I, OE, and Net Profit (NP), Return On Investment (ROI) is intuitively straightforward. T generates money, I invests money and OE spends money.

$$NP = T - OE \quad (1)$$

$$ROI = T - OE + I \quad (2)$$

T, I, OE, can also be used for

another set of measurements - Productivity (P) and Inventory Turns (IT):

$$P = T \div OE \quad (3)$$

$$IT = T \div I \quad (4)$$

From a practical standpoint as operating expense and/or inventory is reduced, at some point the reductions will limit throughput. Also from a practical point of view any significant reduction in operating expense actually means layoffs. In the shipbuilding (government contracting) environment, reducing inventory is offset by the desire for "Progress Payments."

Shipyards should always emphasize increasing throughput to realize the greatest gains in profits, then reducing inventory, and finally reducing operating expense. By challenging and breaking the assumptions behind the A←B←D↔E arrows in Figures 6, 7 and 8 the correct courses of action can be established.

### Performance Measurement paradigms

Performance measurements are needed to monitor subsystems as well as complete systems. Traditionally in U.S. shipbuilding this has been performed under two types of systems. Gessis, 1993 describes the U.S Navy's "Cost/Schedule Control System (CS<sup>2</sup>), and Karlson, 1992 describes the Maritime Administration's (MarAd), Ship Project Monitoring System, also called the 10,000 points system. Variations of both of these systems have been in operation for quite a few years which has resulted in the developing of very strong paradigms. However, a cursory review of each of these system's reveals that their foundations are based on the analytical approach and independent variables. Figure 8 and Table VII relate to this measurement conflict.

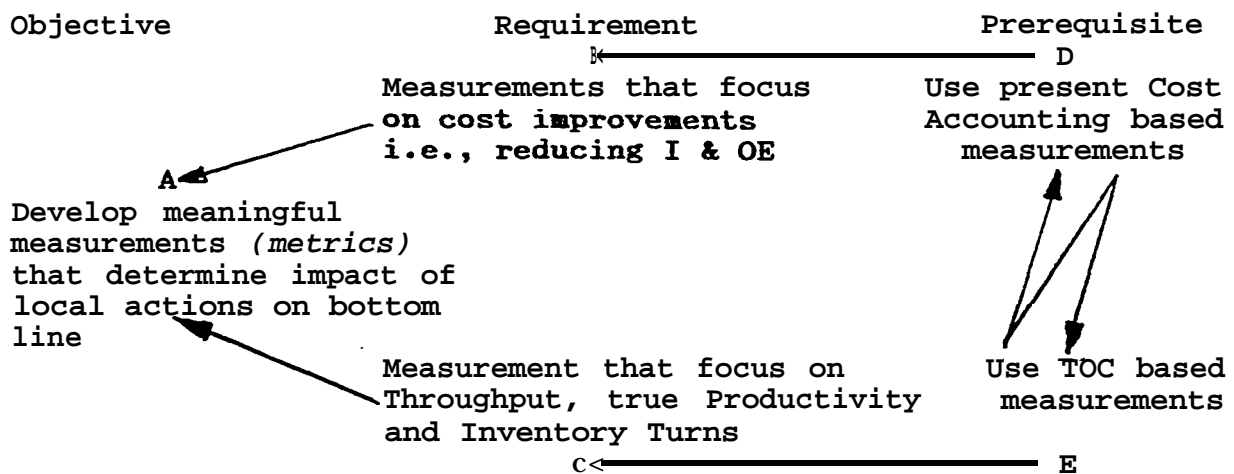


Figure 8 Measurements, Evaporating Cloud Diagram

EC Assumptions	Traditional methods for measuring variance to schedule dates, budget performance, number of delivery dates missed, number of plans late to schedule issue dates, etc., all essentially are a measure of performance against the individual standard (schedule and/or budget) assigned to each item and all deviations basically carry the same significance (weighted value). Since all these measurements apply to each independent item, the negative impact of this dependency on other items is not measured. TOC methods provide measurements in terms of both relative importance to the bottom line (Throughput) and relative to variances from a valid schedule using Throughput and/or Inventory Dollar Day methods (Goldratt and Fox, 1988).
A+B Significant bottom line impact can be gained by reducing costs .	The effectiveness of TOC methods depends on two prerequisites:
IW+D Present Cost Accounting measurements are satisfactory for measuring <i>reduced costs</i> at local levels.	1. an accurate material cost, &
D - E Same as B:D above.	2. a valid schedule.
Reason Assumption is Erroneous	Us. shipyards can meet the first prerequisite, but not the second because the scheduling methods used are based on time as being the driver instead of using exploitation of the constraints as the driver (Goldratt, 1990).
A+B Reducing costs do not have significant impact on bottom line and reducing OE costs really equate to laying off people-an organization's most important resource.	Existing local measurements, like: worker's efficiency and process or schedule variances; encourage rather than suppress doing things that
B-D Local improvements that reduce costs have little impact in bottom line as improvements are usually made in non-constraint areas. Present cost accounting and/or Activity Based Costing (ABC) methods provide erroneous measurements.	
D-E Same as B:D above. TOC measurements provide accurate measures and also by using TOC "Control Measurements" variance to schedules and true accountability is measured.	

Table VII EC Assumptions and Reason Assumption is Erroneous

should not have been done (Goldratt and Fox, 1988). In addition, the progress payment clauses in most ship construction contracts results in a tremendous buildup of inventory in U.S. shipyards because the schedules do not differentiate the critical work required to support the flow of work through the constraint resources and the critical chain. The magnitude of the negative impact on true costs and schedules therefore can not be measured. The TOC control measurement concepts can be fully explained only after the concept and procedures of buffer-management are understood (Goldratt, 1990).

TOC measurements also identify another important paradigm shift that needs to be made in the area of capital expenditures. The role of non-constrained activities within an organization is to support the constraint in the best way possible. All capital expenditure requests for new equipment that will be used in unconstrained areas should be analyzed to ensure that the proposed expenditure will not result in diminishing the capability of the non-constraint area to support the constraint. This analysis is particularly relevant if the proposed new purchase involves consolidating similar activities, as flexibility and responsiveness may be lost. In addition, changing the traditional erroneous practice of justifying capital expenditures based on improving non-constraint performance should be discontinued.

#### Production Paradigms

Many millions of dollars are spent each year in U.S. shipyards on facilities, computerization of systems and other non-constraint equipment.. These major investments in most cases have not resulted in making U.S.. yards competitive in the commercial world market. One major area recognized as contributing to improved productivity and reducing construction time is

where the ship construction work is performed. The two lists of "Difficulty Factors" shown in Table VIII are representative of the magnitude of the savings that can be realized by moving construction work earlier in the schedule.

Location	(A)	(B)
In Shops	1.0	1.0
On Platen	1.5 to 3.0	5.0
Erection Area	4.5 to 7.0	10.0
In Water	10.0 to 15.0	20.0

Table VIII Ship Construction  
"Difficulty Factors"

Reference (A) Wilkins, Kraine, and Thompson, 1993.

Reference (B) Snodgrass, 1982.

For example, if an item can be installed in a shop as opposed to doing the work in the water, the labor hours would be reduced by a factor of between 10 to 15 or 20 (Table VIII). The magnitude of bottom line benefits resulting from moving work earlier (WE) can result only if two necessary conditions are present: (1) the work that is moved earlier is in the critical chain and (2) the ship construction schedule (delivery) is reduced to reflect the productivity improvements. If this work is not in the critical chain then the benefits that could be realized will likely be lost due to other delays encountered before ship delivery. Likewise, if the overall schedule time is not reduced the shipyard workers will work to the issued schedules with very little bottom line impact.

A 1982 barge construction project (Rack, 1982) provides a good example of not only the WE concept, but also illustrates two other concepts that can significantly reduce ship construction time: Work In Parallel (WIP) and In Multiples (IM). WIP is defined as performing similar operations at the same time in another work station.

improvement programs would look like the "B" curve in Figure 9. In reality, very few non-linear programs have been implemented because they require a redesign of the existing system and management's recognition that they must change before the system can be changed (Walton, 1986).

The practical rate of improvements of continuous non-linear processes will take the appearance of the Figure 9 "C" curve. The plateaus in the "C" curve represent the time required before an organization identifies the next "weakest link" (constraint) and implements a satisfactory solution.

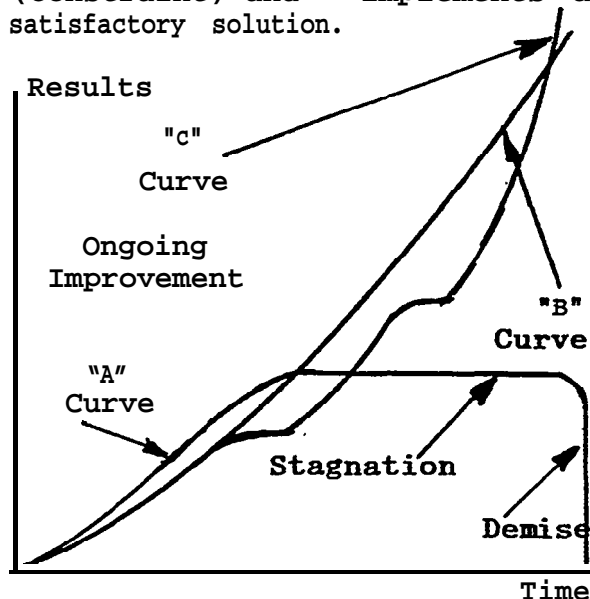


Figure 9. Rates of Improvement

Source: Goldratt. 1990)

All of these referenced approaches have documented improvements of varying degrees. However, these improvements become the new paradigms and sooner or later, every paradigm begins to develop a very special set of problems with no evident solutions. New paradigms put everyone practicing the old paradigm at great risk. The higher one's position, the greater the risk. The better one is at that paradigm, the more one has to lose by changing

paradigms, a condition called "paradigm paralysis" (Barker, 1992).

The actual bringing about of a paradigm shift in an organization, requires:

1. Creating and sustaining the motivations for appropriate changes.

2. Creating, in the organization, the capacity for appropriate thinking.

Both of these items require, in turn:

3. Creating the atmosphere and developing the capacity for open communications, which allows for an in depth reevaluation of hidden assumptions, individually and collectively" (Malin, 1992).

One has only to look at how U.S. shipyards are organized (pyramids with many functions and many levels within each function) and how they have been operating (analytical thinking) for many years to appreciate the magnitude of the paradigm paralysis that has resulted and why it is so difficult to stimulate internal innovation. So, until U.S. shipyards can change that attitude and stimulate their people to be more flexible and break out of their paradigms to search for alternatives, the great new ideas will probably be discovered outside the shipyard's organization (Barker, 1992).

The various necessary conditions that have to be present to cause change include: (Malin, 1992)

1. Aspiring goals,
2. Motivation,
3. Togetherness,
4. Ownership,
5. Appropriate thinking (having the necessary knowledge and having the right methods and capacity to use them ),
6. Communications,
7. Organizational cooperation instead of competition, and
8. Greatly expanded use of dialogue.

The dialogue expansion includes:

1. open listening,
2. looking at one's thoughts.

which arise in response or reaction to

others' pronouncements, and in particular,

3. discovering the hidden assumptions, the paradigms behind one's thoughts, and

4. being willing to suspend these assumptions.

Deming, (Stevens, 1994) expressed thoughts on how to cause change: [With only inside understanding] "What you do is only to dig deeper the pit you are in...To get out of the pit we require an outside view. No chance from the inside. A system cannot understand itself. Understanding comes from the outside. An outside view provides a lens for examination of our present actions, policies... (Bold added) Knowledge from outside is necessary. Knowledge from outside gives us a view of what we're doing, what we might do, a road to improvement, continual improvement."

An essential part of change in any organization, any group . . . is the creation of conditions in which people can explore the fixity of their own thoughts, the confusion between "presentations" and "representations," the real nature of what they call "facts," etc. Such conditions are the prerequisites for communications among members of the group, communication which is, in turn, a precondition for change (Malin, 1992).

U.S. shipyards have been operating for many years in accordance with systems that are based on analytical thinking, independent variables and knowledge gained from an educational system that: "what they teach is continuance of our present methods of management, which are failures. They teach how to fail, how to continue to fail", (Walton, 1992).

This situation is made worse because of the strong paradigms practiced by U.S. shipyard managers and workers and by working to a system designed to meet contract requirements. Many of these contract requirements are based on a different set of objectives to meet a different

"set of rules" (goals) than those of the shipyards.

The key and major paradigm shifts that are considered necessary to meet the present situation facing U.S. shipyards were discussed earlier in this paper.

However, "When our frames of reference are fixed and rigid, they become a substitute for thinking. Learning takes place when we have flexibility to change our frames of reference. The most creative efforts of human beings involve departing from existing frames of reference and constructing new ones", (Rubinstein, 1985).

The flexibility for learning in U.S. shipyards has been restricted by this paradigm paralysis. This condition has prevailed for many years because much of the technology being used by managers has been proven to be not only very fixed and rigid but is also flawed in that it has led to "Cost World" results (Rack, 1991).

Significant immediate profits can be realized through productivity improvements by making certain paradigm shifts such as implementation of the WE WIP IM concept-s, increased manning and/or number of shifts worked and also other physical (facility) changes.

To implement and sustain true continuous non-linear and linear improvement processes a paradigm shift from paradigm paralysis (hear nothing but threats) to paradigm pliancy (hear nothing but opportunity) is necessary, (Barker, 1992).

To paraphrase Swartz, 1994, U.S. shipbuilders have to develop The Non-Linear Solution:

To become a WORLD LEADING COMPETITIVE SHIPBUILDER one must TRANSPORM THEMSELVES (managers and workers) and then the BUSINESS in order to MAXIMIZE the RATE and QUALITY of LEARNING and IMPROVEMENT.

IM is defined as doing multiples of the same operation in the same work station with essentially no increase in time or manhours.

The combination of these three concepts results in the possibility of having the combination of three multipliers instead of just the WE multiplier (WE X WIP X IM v. WE).

Once again the controlling factors (necessary conditions) are that the multipliers are only effective if the work is in the critical chain and the overall schedule time is reduced.

The author (Rack, 1982) was not aware of the TOC at the time this barge facility was designed. However, the concepts used can be compared to the TOC Drum-Buffer-Rope (DBR) technology (Goldratt, 1990). This concept also meets both necessary conditions.

The Drum is the perceived market requirement of a barge every other day (2 day deliveries). The barge facility has 52% excess capacity as it was scheduled to work only 10 shifts (5 days a week, 2 shifts) when 21 shifts (7 days, 3 shifts) are available. This excess capacity means there are no physical constraints in meeting the Drum beat of the market (a barge every other day).

The panel stiffener machine was established as the constraint and became the Drum on which the production schedule was based.

The "Rope" between the Drum and the material release "Gate" determined when material had to be released so that buffers could be established to provide a continuous flow to and from the panel stiffener machine and ensure meeting the Drum beat of perceived market. It was discovered that the only original work station that did not support the continuous flow of one barge every other day was the single rake assembly work station. The solution was to add another station.

Another constraint was the weather. All platen type work had downhand welding of rake stiffeners

was done at the erection position. However, all other outside operations could be delayed by bad weather. Therefore five additional stations were added to accomplish any weather delayed work.

The positive bottom line impact resulting from these three concepts (multipliers), henceforth called: "WE WIP IM" was significant.

Table IX indicates the construction work that was moved earlier from the erection area to the shop and elimination of all platen work.

Potential weekly throughput equated to:

$$5 \text{ days} + 2 \text{ days} \times 570 \text{ tons} = (5) \\ 1,425 \text{ tons per week}$$

Potential yearly throughput equated to:

$$1,425 \times 52 \text{ weeks} = 74,100 \text{ tons} \quad (6)$$

The WIP operations consisted of doing panel welding at both the inlet and exit panel welding stations, simultaneous rake assembly in two stations, and the flexibility of doing any uncompleted outside erection and blast and paint work in the five additional buffer work stations.

IM operations consisted of multiple panel stiffening (up to 9 at a time), tank top plug welding (6 at a time) and the most important operations leading to a significant reduction in construction time and costs-the joining of all erection units in the shop (3 "super" units (1 bottom & 2 sides), Rake & Transom).

Although the above discussion and Table IX data pertain to inland waterways barge construction many of the WE WIP IM concepts can readily be applied to ocean going ship construction. The resulting significant savings in ship construction costs and the large reduction in overall construction time translate to much higher profits.



Operation	Traditional*			WE WIP IM	
	Shop	Platen	Erection	Shop	Erection
Number of Panel Butt Welds (Plate to Plate) 65	54	11	0	65	0
Number of Cycles Stiffeners welded to panels	66(1)	12	0	35	0
Number of Tank Top Plate/Plug Welds 22/1056	0 0	17(2) 816	5 240	21 1008	1 48
Number of Plug Weld Cycles	0	816	240	168(3)	48
Number of Main Assembly Units 17	0	17	0	17	0
Number of Erection Units 17	0	0	17	0	5(4)
Number of Erection Welds 37 (24 Sides, 13 Bottoms]	0	0	37	26	11(5)

\* Traditional Barge construction assumes panel line welder, stiffener tack station (3/6 stiffeners/tacks) and stiffener welder (3/6 stiffeners/welds).

- (1) One cycle = 3 stiffeners v. up to 9 stiffeners.
- (2) Plug welds made in Platen areas v. in shop.
- (3) Special welding equipment (6 weld at same time).
- (4) One Bottom and 2 Sides, plus Rake and Transom.
- (5) 3 Bottom welds, and 8 side welds.

Table IX Traditional Barge Construction V.  
WE WIP IM Concepts

Source: Rack, 1982.

#### HOW TO CAUSE THE CHANGE?

Numerous articles and books have been written ( Barker, 1992, Drucker, 1980 and Swartz, 1994, etc.), that have provided answers to the two questions discussed previously: What to change and What to change to, but the question: How to cause the change, has only been partially answered.

The common message and overall objective of all of these "Gurus" is essentially the same i.e. , continuous on-going improvement. The actual results in all too many cases of continuous on-going linear improvement programs that have been implemented is shown as the "A" curve in Figure 3 and Figure 9 below.

Theoretically the implementation of continuous on-going non-linear

## CONCLUSIONS

The U.S. Shipbuilding industry is a major link in the overall U.S. Maritime industry, but it may well be one of the weaker links. At the global level, a significant contribution to the national economy and to the involved participants can result from continued growth of each and every element in this industry. Leadership to eliminate the traditional adversarial relationships (paradigms) is needed before a concerted effort to develop Win-Win solutions can be implemented.

The vision of each of the elements of the U.S. Maritime industry should be to contribute to the overall sustained growth of this industry. The U.S. shipbuilders can make a major contribution if they become competitive in the world market.

Today's available technology provides an understanding of what has happened, both good and bad, to many industries and nations. This same technology can be used to learn what should be done to improve the future. To make an improvement requires a change. However not all changes are improvements.

The TOC'S Thinking Processes (TPs) provide a "workable tool" that when used in conjunction with "Systems" thinking principles that are directed to implementing the non-linear solution, can result in moving U.S. shipbuilders from the "Reactive Mode" to the "Anticipative Mode" of managing. The following key elements are prerequisites or vital elements of such a process:

1. System Thinking,
2. Outside Knowledge,
3. Communications,
4. Redesign of the System,
5. Assumptions (challenging of),
6. True and Inspiring Goals,
7. Involvement (employees), and
8. Continuous Non-Linear and Linear Improvement.

Proven methods exist to address physical and policy type of constraints. However, how existing technology can be used to address the third type of constraint-behavioral has been the major obstacle as it involves individuals.

Improvement in existing methods are still needed in: "ways to arouse emotional factors, other than fear, that will motivate people to invest the emotional energy needed to bring about the fundamental changes in behavior, as well as in the structure and functioning of the organization" (Malin, 1992).

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# A Production Control System Based on Earned Value Concepts

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## ABSTRACT

In the last four years, Astilleros Espanoles S.A (AES) has completed the implementation of its Shipbuilding Industrial Model based on the use of a Product Work Breakdown Structure for each new construction shipyard. As a logical development of this model, a new Production Control System has been built using Earned Value Techniques. This article describes the state of the implementation of this production control system.

First, the basic structures of the Shipbuilding Model are defined as:

- Product Work Breakdown Structure of each Ship under construction
- Process Breakdown Structure of the Shipyard and : Organizational Breakdown Structure.

Also described is how these structures are reflected in the basic logical concepts of the Production Control System product, process, organization, control accounts and control points, (by product processor organization), work packages and work orders.

The functional description of the Production Control System is explained. Some examples of outputs are presented stressing the method of result analysis prepared for each responsibility level of the shipyard, general manager, production manager, shop and production unit managers.

Next, the development of the implementation phase in one test corporate shipyard is described, as well as the main problems found and the way in which they have been solved.

Finally, some conclusions about the Production Control System are presented, together with several future planned developments for the system.

## NOMENCLATURE

ACWP	Actual Cost of Work Performed
AESA	Astilleros Espanoles S. A
BAC	Budget at Completion
BCWP	Budgeted Cost of Work Performed
BCWS	Budgeted Cost of Work Scheduled
CCA	Cost Control Account
CPI	Cost Performance Index
CSC	Cost Schedule and Control System

## EAC

IEAC  
NSRP

## OBS

## PAM

## PBS

## PIMET

## POAM

## PWBS

## TCPI

## WO

## WP

Estimate at Completion

Independent Estimate at Completion

National Shipbuilding Research Program

Organizational Breakdown Structure

Process Assignment Matrix

Process Breakdown Structure

Plan Integral de Mejoras en Tecnologia (Integrated Technology Improvement Plan)

Product Assignment Matrix

Product work Breakdown Structure

To complete Performance Index

work order

Work Package

## INTRODUCTION

In the last four years, an important effort has been completed design, develop and implement a Shipbuilding Industrial Model, based on the use of zone and stage prediction technology, flexible production planning and scheduling, and product oriented breakdown Structure. As a necessary development for this industrial model, a specific project was started with the target to design and implement a new Production Control System, based on the application of these related techniques and the use of Earned Value concepts.

For this purpose, a specific team was created, which assumes as its basic target the modification of the conventional 'Activity' concept to the new 'Product' concept

This team connection with the factory production team, developed a new production organization process, based on the use of interim products as planning and scheduling units. Each Interim Product takes the place of an old activity planning element and introduces a new relationship between the three basic elements related to the production frame

- Product as the element to be done,
- Process, as the way to produce using Group Technology rules, and
- Organization, as a specific group in charge of getting the product finished.

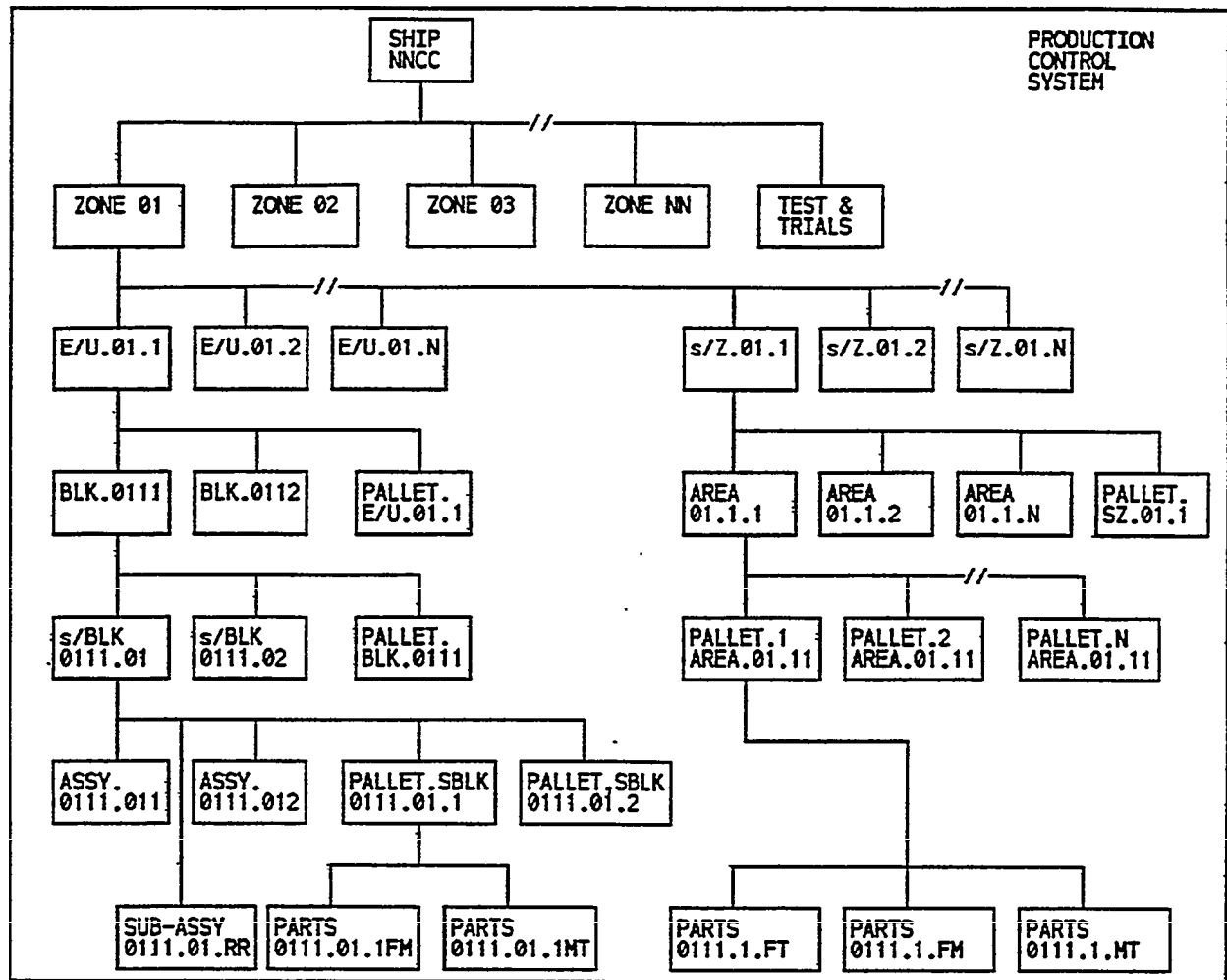


Figure 1.A sample Product Work Breakdown Structure

The second basic concept, Earned value, introduces a complementary innovation on the conventional production control, in the fact that the production progress is measured by the individual progress of each product scheduled. Earned value concepts and methods are not described, since they are well known and enough bibliography exists on them. What is shown is their practical application to new construction control in shipbuilding

The use of Group Technology concepts, allows, besides a better industrial production performance, a more accurate estimation of future results, based on actual performances for each considered group. The relationship between product process and production units (Organization) has been established under the rules of Group Technology.

The new Production Control System changes the old concept of 'results measurement' to the new 'production Management', providing continuous information on cost and schedule variations on each product, at each product level considered, and a complete analysis of production performance and productivity parameters.

This project is included in a larger Productivity and Competitiveness Improvement project which has its origin in the PIMET project (Plan Integral de Mejoras en Tecnologia or Integrated Technology improvement Plan), performed along the last five years, using some ideas the National Shipbuilding Research Programme (NSRP) programmes and documentation.

## THE PRODUCT ORIENTED WORK BREAKDOWN STRUCTURE

It is not considered necessary to redefine the Interim Product concept that has been very well established in the NSRP papers. In this paper only will be described the way this concept has been taken and applied to commercial shipbuilding, like a sophisticated oil carrier.

In the beginning of the project a Product oriented Work Breakdown Structure (PWBS) was developed for a shuttle oil carrier, that was being built in the test ship. Each finished element was defined as a 'product' integrating steel and outfitting works, whose integration with other

products, or elemental components, produces a new and more complex product Figure 1 shows this basic concept which is applicable to any other ship.

Following this, any product at any level can be identified, and each of these products can be taken as 'control point' selecting the most convenient level in accordance to production control needs.

## THE PROCESS BREAKDOWN STRUCTURE

The following step was the production process identification and definition. Process is defined as the way to produce a specific product or element applying Group Technology concepts. Each shipyard has its own Process Flow, and its own Process definition

This process structure defines the Shipyard Production Structure through the identification of their Production Processes, all characterized by Group Technology concepts.

The main characteristics considered in the process definition are that it be:

Group Technology based,  
Clearly identified and  
Stable in efficiency parameters.

Under these concepts, the Process Breakdown Structure (PBS) of each shipyard has been developed, taking into account the functional differences, and the specificity of each of them. Figure 2 describes the basic scheme of these breakdown structures.

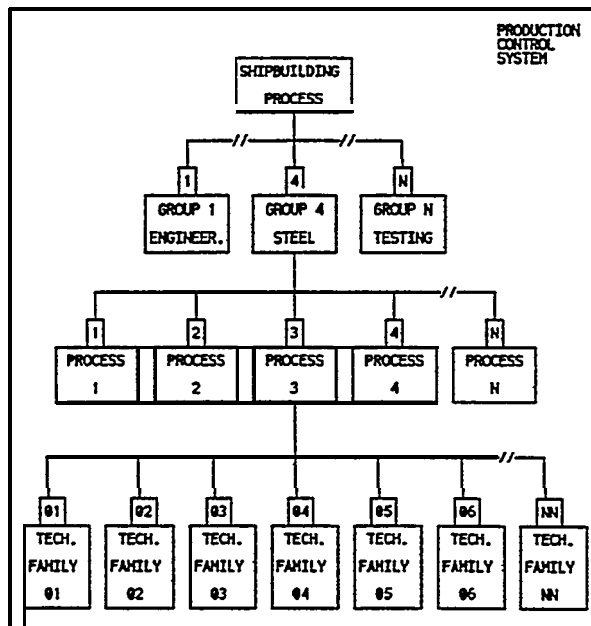


Figure 2. A sample of Process Breakdown Structure

As an example of a third level definition Technological Family, Table I shows the considered Technological Family

of the steel processes in the test shipyard.

A very-simple numerical codification system has been used to easily identify processes. In general terms, to produce a specific product it is necessary to perform tasks belonging to several processes.

Each process is assigned one or several units directly related to the amount of work required to carry out the task. For instance, the numbers of thin and thick pipes are considered reasonable units for the estimation of work for an outfitting job (e.g. welding pipes of welding thicknesses), that has been defined as a process at a certain level.

## THE ORGANIZATIONAL BREAKDOWN STRUCTURE

The Organizational Breakdown Structure (OBS) describes the structural organization of each Factory, and shows the different responsibility levels. This is a typical OBS, and in general terms is the same for all corporate shipyards. Figure 3 shows a typical OBS of a shipyard.

In this structure Production Unit is defined as a workshop or a workshop part, with facilities and utilities especially arranged for one or more technological processes, with Professionally trained Workers, and with their own process specifications, production procedures, dimensional accuracy systems, quality procedures and controls.

Each production unit is specialized in one or more processes, and produces one or more types of interim Products, under the most convenient production conditions, and with the best production performances. It is also possible for similar products to be made in two or more production units, with equal or similar processes, but normally the production performances are not equal.

## THE PROCESS ASSIGNMENT MATRIX

Crossing two basic structures, the Process Breakdown and the Organizational Breakdown Structures, a Process Assignment Matrix is obtained defining for each production unit the processes that the unit performs. Another layer of the matrix defines production performances expected of each production unit and specific process.

To estimate the required manhours for a given task two steps are followed. First, the quantities of the chosen units are determined. Second, an expected efficiency for each unit of measurement at the production unit is applied. This efficiency is taken from previous experience of the Yard, taking into account the procedural modifications to be made in each particular case.

This matrix enables one to plan the most convenient way to produce interim products or elements for each project in accordance with the work charge of the different workshops. Also provides an easy procedure to determine the differential costs derived from changes in the work assignments.

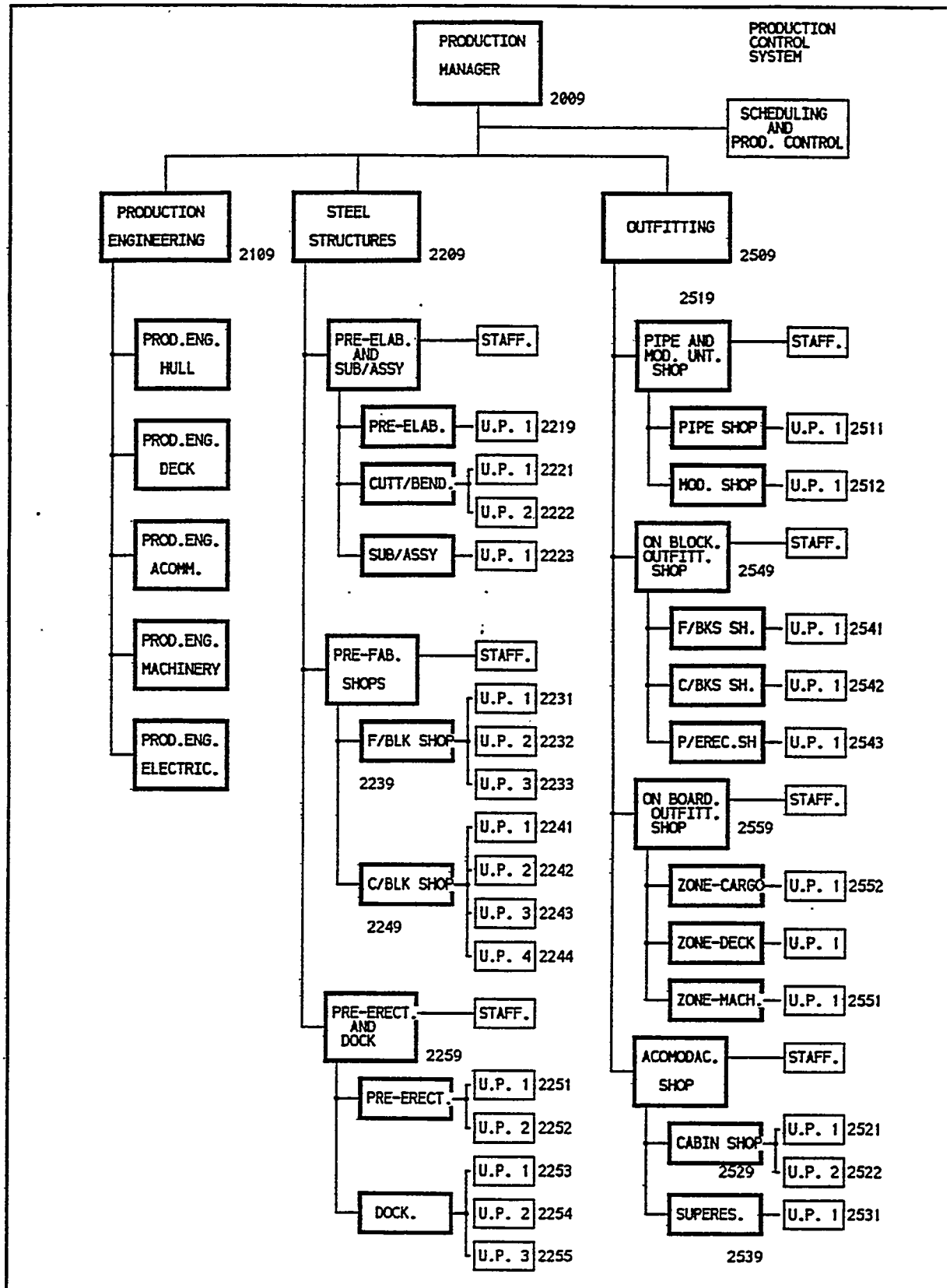


Figure 3. A sample of Organizational Breakdown Structure

TECHNOLOGICAL FAMILIES, PROCESSES AND GROUP IDENTIFICATION							
GROUP	PROC.	TECH. FAMILY	DESCRIPTION	UNIT 1	UNIT 2	PARAM. 1	PARAM. 2
4			Steel				
	4.1		Pre-elaboration				
		4.1.01	Sheet Pre-elaboration	Ton(gross)		Hrs/ton	
		4.1.02	Shape Pre-elaboration	Ton(gross)		Hrs/ton	
	4.2		Cutting				
		4.2.01	Sheet cutting for sub-assembly	Ton (net)	m.	Hrs/ton	Hrs/m.
		4.2.02	Sheet cutting for assemblies	Ton (net)	m.	Hrs/ton	Hrs/m.
		4.2.03	Shape cutting for sub-assembly	Ton (net)	# parts	Hrs/ton	Hrs/part
		4.2.04	Shape cutting for flat panels	Ton (net)	# parts	Hrs/ton	Hrs/part
		4.2.05	Shape cut & bending	Ton (net)	# parts	Hrs/ton	Hrs/part
	4.3		Bending				
		4.3.01	Sheet bending (simple)	Ton (net)	# parts	Hrs/ton	Hrs/part
		4.3.02	Sheet bending (normal)	Ton (net)	# parts	Hrs/ton	Hrs/part
		4.3.03	Sheet bending (complex)	Ton (net)	# parts	Hrs/ton	Hrs/part
	4.4		Sub/sub assembly production				
		4.4.01	Automatic sub/sub assembly line	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.4.02	Sub/sub assembly line	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
	4.5		Panel fabrication				
		4.5.01	Flat panel assembly	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.5.02	Shape inserts.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.5.03	Curved panel assembly	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
	4.6		Subassembly fabrication				
		4.6.01	Flat subassembly line	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.6.02	Curved subassembly line	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.6.03	Special subassembly line	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.6.04	P/p subassembly line	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
	4.7		Sub block prefabrication				
		4.7.01	Simple flat sub block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.7.02	Normal flat sub block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.7.03	Complex flat sub block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.7.04	Simple curved sub block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.7.05	Normal curved sub block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.7.06	Complex curv. sub block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.7.07	Special curved sub block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
	4.8		Sub block prefabrication				
		4.8.01	Simple flat block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.8.02	Normal flat block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.8.03	Complex flat block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.8.04	Simple curved block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.8.05	Normal curved block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.8.06	Complex curved block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.8.07	Special curved block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.8.08	Superstructure block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.

Table I. A sample of technological families and measurement units for steel manufacturing processes



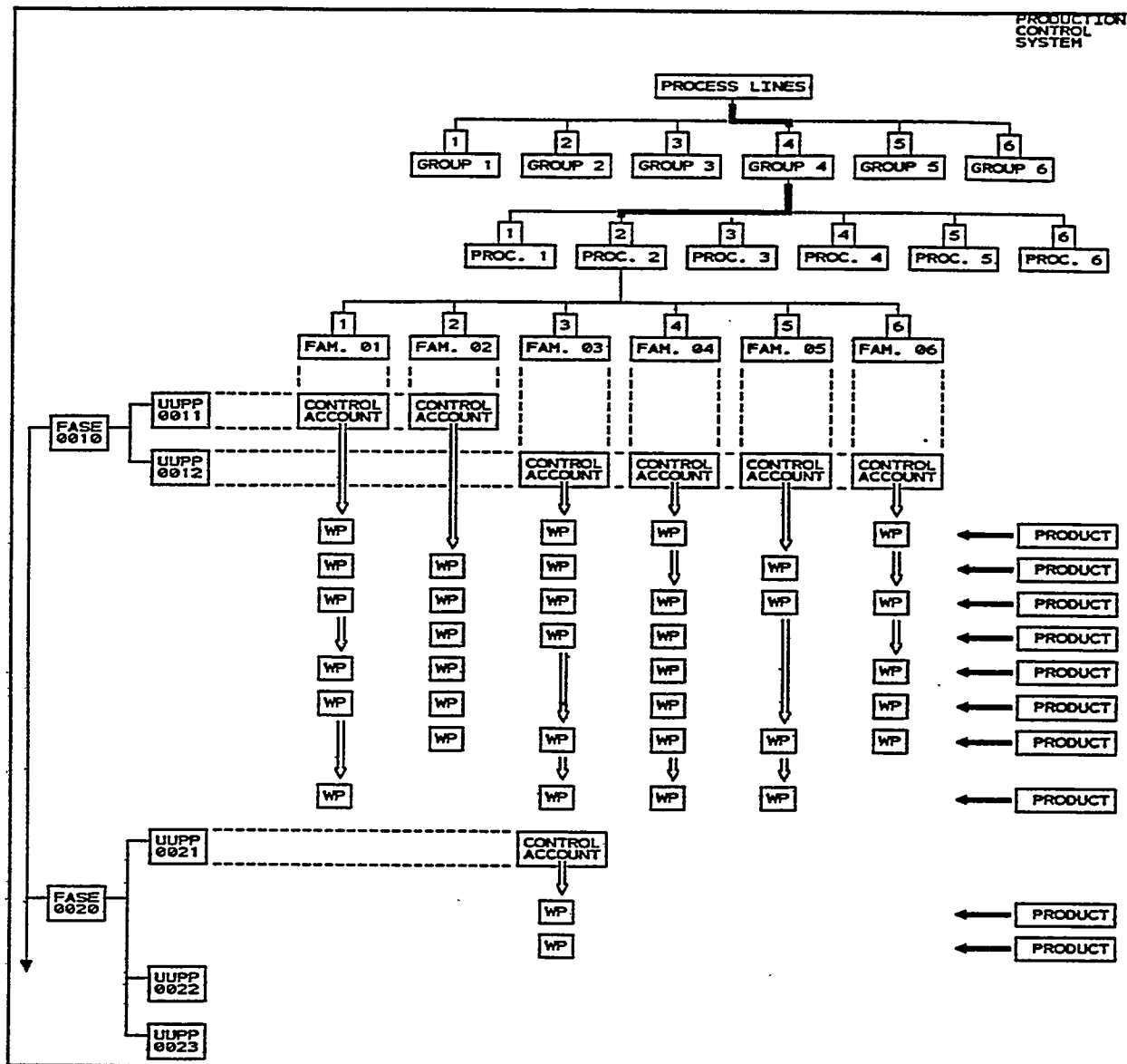


Figure 4. A sample of a Product Assignment Matrix

### THE PRODUCT ASSIGNMENT MATRIX

The second matrix developed, is the Product Assignment Matrix, crossing the project Product Work Breakdown Structure with the Process Assignment Matrix. The project PWBS shows, for each specific ship under construction, all interim products that must be done for this ship. Crossing this PWBS, for each one of the products, with the Process Matrix, it is possible to determine:

- What Products will be made,
- What Process will be applicable,

- What Production Unit will be in charge, and
- How much will it cost.

This matrix answers the four basic questions raised

- What?,
- How?,
- Who?, and
- How much?.

An example of this matrix is shown in Figure 4. From this matrix it is possible to define all the control points, as well as to determine all the work packages.

## WORK PACKAGE

The Work Package (WP) is defined as the amount of work of a process to be done by a production unit to obtain a product. That means that a finished product is the sum of different work packages, each work package belonging to a specific process and a prediction unit

Using the NO assignment matrices previously developed, it is possible to define the work packages for each product taking into account the following basic rules:

- Each WP only belongs to a Product
- Each WP only belongs to a specific process,
- Each WP contains a predefined work contents and its corresponding budget
- Each WP must be scheduled,
- Each WP only belongs to a specific Production Unit and must have only one person in charge,
- The size and duration of each WP only depends on the characteristics of the work involved and the conveniences for its control.

Figure 5 shows a typical definition of work packages for a product. Also Figure 6 shows the code used in the test shipyard to describe each WP.

## WORK ORDER

A Work Order (WO) is the interface of the System with the shop. A WO contains the technical description and the time frame for specific task of a certain process, to be performed by a production unit.

A work order is the lowest level control element used in this Production Control System and is the basic element in calculating performance and conducting the production process.

Some important characteristics to be considered when defining work orders are listed below.

A WO is a logical work unit to be executed by a production unit in a practical and reliable manner.

A WO must have a logical start and termination, because it is the basic measure for the progress of the project. When the order is completed there should not be any doubt as to the work accomplished. For this reason, the WO must be defined in utmost detail with reference to the work content and extent, including all corresponding technical information as well as special instructions, material list, pallet list etc.

A WO must have a short duration normally no more than two weeks and a small work content, not more usually than 200 man-hours.

A WO must not be stopped when it has been started. A WO must be done in the exact way that has been planned. If necessary changes must be made, it is

better to cancel the WO and produce a modified new one.

Precision in defining work orders, as well as accuracy in capturing results is the key for a reliable system, and a reliable estimation of final results.

This production control system has defined the following WO types.

- Normal or typical WO, belongs to an unique WP. It is a part of the WP, with a clear definition of the tasks it includes, so that its completion is easily checked. All the tasks in the WO belong to the same process than the WP. This type of WOs represent the majority of edited Work orders.
- Distributed is one WO which belongs to two or more WPs, always made by the same production unit. Its use is restricted to WPs With Small Work Contents whose individual control is difficult
- Service, is one WO corresponding to support works. The hours charged to these WOs are distributed among all the WOs being in execution during their duration period

Normal and distributed WOs may be subcontracted, and the program contains a specific module to deal with this situation.

Figure 7 shows the form used to define and edit WOs in the test shipyard

There are three important criteria applied to the WO definition.

- There should be, as a minimum, one Work Order for each Work Package.
- The sum of WO budgets for each WP should be equal to the WP budget including those distributed WOs dated to the WP.
- The sum of WO work contents for WP should also be equal to the WP work content, including the distributed WOs related to the WP. The schedule of a WO must also be coherent with the schedule of the WP (WPs, in case it is distributed) i.e. which it is derived

In summary, the WO represents an unmistakable work unit which must be performed without disturbances, and under the supervision of a unique responsible person. As the WO has an identified work content, it must have a fixed budget and an integrated schedule.

## COST CONTROL ACCOUNTS

Cost Control Accounts (CCA) represent the visible expression of the Control Points, and allows the management of the different project parts by the way that the Project has been divided

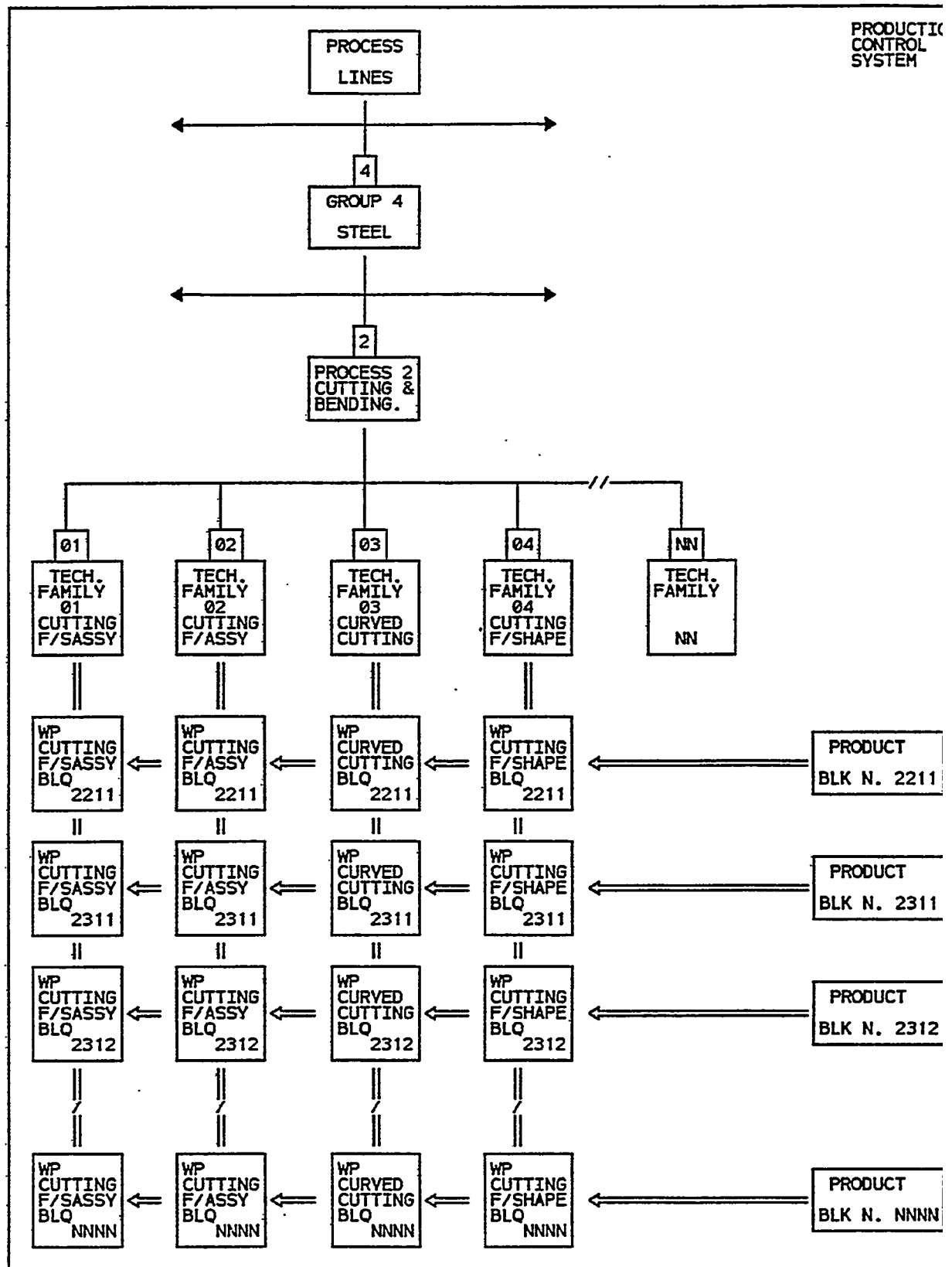


Figure 5. A sample of Work Package definition

## ASTILLEROS ESPAÑOLES S.A.

PRODUCTION  
CONTROL  
SYSTEM

### WORK PACKAGE

PACKAGE n°	333
GROUP	1
PROCESS	1
TECH. FAM.	22
PRODUCT	88888888
OBS-FASE	4444
OBS-UUPP	4444

SHIP n° \_\_\_\_\_

W.PACKAGE.

UUPP

FASE

PRODUCT

TECH. FAMILY

PROCESS

GROUP

W.P Number

BUDGET
\_\_\_\_\_

TOTAL BUDGET.....
\_\_\_\_\_ Hrs

WORK DEFINITION	UOH <sub>1</sub>	UOH <sub>2</sub>	UOH <sub>3</sub>	UOH <sub>4</sub>	UOH <sub>5</sub>	UOH <sub>6</sub>	UOH <sub>7</sub>	UOH <sub>8</sub>	UOH <sub>9</sub>	UOH <sub>10</sub>	UOH <sub>11</sub>	UOH <sub>12</sub>
UNIT												
CODE												
QUANTITY												
PARAMETER												
TOTAL												

SHORT DESCRIPTION

DETAILED DESCRIPTION

**WORK PACKAGE SCHEDULE.**  

START.
\_\_\_ / \_\_\_ / \_\_\_

FINISH .
\_\_\_ / \_\_\_ / \_\_\_

MADE BY:
\_\_\_\_\_

DATE:
\_\_\_\_\_

APPROVED BY:
\_\_\_\_\_

DATE:
\_\_\_\_\_

CHANGED BY:
\_\_\_\_\_

DATE:
\_\_\_\_\_

APPROVED BY:
\_\_\_\_\_

BAR n°
\_\_\_\_\_

**BUDGET DISTRIBUTION METHOD.**  
 1.- LINEAL  
 2.- FIX PERIODS.(% BUDGET @ 50% PERIOD)  
 3.- SPECIFIC BUDGET CURVE

PER	FROM	TO	QUANTITY
1	___ / ___ / ___	___ / ___ / ___	
2	___ / ___ / ___	___ / ___ / ___	
3	___ / ___ / ___	___ / ___ / ___	
4	___ / ___ / ___	___ / ___ / ___	
5	___ / ___ / ___	___ / ___ / ___	
6	___ / ___ / ___	___ / ___ / ___	
7	___ / ___ / ___	___ / ___ / ___	
8	___ / ___ / ___	___ / ___ / ___	
9	___ / ___ / ___	___ / ___ / ___	
10	___ / ___ / ___	___ / ___ / ___	

Figure 6. A sample form used for Work Package definition

ASTILLEROS ESPAÑOLES S.A.		PRODUCTION CONTROL SYSTEM																																				
<b><u>WORK ORDER</u></b>																																						
<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">WORK PACKAGE NUMBER..... 333</div> <div style="border: 1px solid black; padding: 2px;">WORK ORDER NUMBER..... 666666</div>	<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">SHIP Number..... 333</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">GROUP..... 1</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">PROCESS..... 1</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">FAMILY..... 22</div> <div style="border: 1px solid black; padding: 2px;">PRODUCT.....4444</div>	<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">FASE..... 4444</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">UOPP..... 4444</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">BLOCK.....4444</div> <div style="border: 1px solid black; padding: 2px;">S/ZONE.....4444</div>																																				
<div style="border: 1px solid black; padding: 2px; display: flex; justify-content: space-between;"> <span>WORK ORDER TOTAL BUDGET..</span> <span>Hrs</span> </div>																																						
<div style="border: 1px solid black; padding: 2px;">WORK ORDER TYPE: NORMAL/DISTRIBUTED</div>																																						
<div style="border: 1px solid black; padding: 2px; min-height: 30px;">SHORT DESCRIPTION.</div>																																						
<div style="border: 1px solid black; padding: 2px; min-height: 150px;">DETAILED DESCRIPTION.</div>																																						
<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">WORK ORDER SCHEDULE</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">START.            _ / _ / _</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">FINISH.          _ / _ / _</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">WORK ORDER ACTUAL DATES</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">ACTUAL START    _ / _ / _</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">ACTUAL FINISH   _ / _ / _</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">MADE BY</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">DATE:</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">AUTHORIZED BY:</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">DATE:</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">FINISHED BY:</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">DATE</div> <div style="border: 1px solid black; padding: 2px;">CLOSED BY:</div>		<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">WORK ORDER CONTENT:</div> <table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr> <th style="width: 15%;"></th> <th style="width: 12.5%;">UOM 1</th> <th style="width: 12.5%;">UOM 2</th> <th style="width: 12.5%;">UOM 3</th> <th style="width: 12.5%;">UOM 4</th> <th style="width: 12.5%;">UOM 5</th> <th style="width: 12.5%;">UOM 6</th> </tr> </thead> <tbody> <tr> <td>UNIT</td> <td></td><td></td><td></td><td></td><td></td><td></td> </tr> <tr> <td>CODE</td> <td></td><td></td><td></td><td></td><td></td><td></td> </tr> <tr> <td>QUANTITY</td> <td></td><td></td><td></td><td></td><td></td><td></td> </tr> <tr> <td>TOTAL.</td> <td></td><td></td><td></td><td></td><td></td><td></td> </tr> </tbody> </table> <div style="border: 1px solid black; padding: 2px; min-height: 80px; margin-top: 5px;">REMARKS.</div>			UOM 1	UOM 2	UOM 3	UOM 4	UOM 5	UOM 6	UNIT							CODE							QUANTITY							TOTAL.						
	UOM 1	UOM 2	UOM 3	UOM 4	UOM 5	UOM 6																																
UNIT																																						
CODE																																						
QUANTITY																																						
TOTAL.																																						

Figure 7. A sample form for Work Order definition

A CCA inside the system is defined by a certain selection of Work Packages, and different selections of WPs produce different types of CCAs. It is possible to sum the WPs belonging to a product, and have a CCA

specific product as for a process or for a production unit. The codification system for the WP, which includes characterization blocks for product, processor production unit permits all the possibilities, and renders this system flexible and reliable.

## FUNCTIONAL STRUCTURE OF THE PROGRAM

The program has been developed with modular organization concepts. In this way it has been possible to use some modules while others were in the development stage. In the paragraphs that follow modules are described in the generic order they are used when controlling a new construction project.

### Project Definition Module

The objective of this module is to allow a user to define a project. This definition includes the specification of the work to be performed (and of the required manpower), the departments responsible for it and its scheduled time distribution. The final product of this module is a performance measurement baseline, that relates the accumulated manpower to be used with time. This baseline may consider the whole project or maybe built by product process, organization or any combination of them.

In the terms described so far, it is possible to state that this module allows a user to specify for a project the Interim Products of the Work Breakdown Structure, the Process Breakdown Structure, the Organizational Breakdown Structure, the Process Assignment Matrix and finally, the Product Assignment Matrix.

While the project progresses, a more detailed knowledge is obtained about the work that is necessary for each interim product. Typically, three situations are considered for the project. The first one has available the information that is generally known at the time a contract takes effect. The second situation considers the information at the time the building strategy is fixed and the third one has available all the information contained in the detailed design.

The specification of a project may be done at any of the situations referred to. The later in a project life the more detailed the information will be. Then it is possible to build Work, Process and Organizational Breakdown Structures, and Process and Product Assignment Matrixes for each of these situations, although the level of detail will vary.

The monitoring of performance is carried out at the most detailed level, in order to obtain maximum accuracy. However, it has been considered useful to include in the module the possibility of specifying the project at the initial levels, with two objectives

To distribute the budget entirely and have a global vision of a project at any time, although with a smaller level of detail, and

- To obtain performance estimates referring to the processes and units of measurements defined for the initial levels, once the final results are known. These performance ratios are used for estimates of future ships, thus feeding the estimation cycle with actual results.

The result of this module is a database containing the above mentioned structures plus the work packages for each level of specification selected. The databases are related in such a way that, for a given product, it is always possible to compare the work packages obtained at different levels.

The product process and organization structures are defined as hierarchical structures. There is a set of program utilities for the management of this kind of structures, allowing users to create or modify them with the minimum restrictions to assure their integrity.

Another set of utilities is provided for the management of the work packages. This allows users to create, modify, list, graph, etc, the work packages of every database. Also it is possible to obtain numerical and graphical expressions of any performance baseline by process, product or organization.

Another utility of the module allows the handling of the management reserve. Exchanges between work packages and management reserve are possible in both ways, with all the necessary cautions to maintain the integrity of the system. It is possible to obtain detailed reports of the evolution of the management reserve, as well as of records showing the nature of all changes carried out.

The module allows the connection with the planning and schedule systems in some of the shipyards. However, a high degree of manual handling of work packages is still needed, for at present there is not a unified approach to planning in all the new construction shipyards using the system.

### Work Order Issuing Module

Work orders are the interface of the system to the shops. The production system of the shipyard does not need acknowledge of the Product Assignment Matrix or of any of the structures used by the system. All work packages are broken down (or grouped) into work orders, that are issued to the shops approximately three weeks in advance of their scheduled beginning. It is up to the shops to prepare a detailed programming of their work, with the orders they have received.

The normal WO module makes sure that each WO complies with the restrictions on the quantity of work imposed by the work package it is related to. For distributed work that belong to several work packages, the proportion of effort assigned to each work package is recorded, with a check on the suitability of the assigned workload.

The utilities included in the module allow easy handling of new or existing orders, including creation modifica-

tion, issue, opening and closure of work orders. The module offers users the possibility of customizing reports on work orders issued, or on work orders in various states of readiness, such as approved but not issued, pending approval, in process, due finished or closed. It is possible to limit the scope of reports in the customary way to any combination of the product process and structure organizations. Furthermore it is possible to obtain reports about the orders issued for each work package, thus allowing the controller to be aware at anytime of the degree of fulfillment of a given work package.

#### Subcontracting Module

The system has a specific treatment for subcontracted work orders. Normal and distributed work orders may be assigned to subcontractors. They are included in the system in every respect, although reports concerning these orders are kept separate from orders carried out in the same shipyard. It is possible to obtain a combined report on completed work and, once subcontracted orders are finished to compare their costs with similar orders not subcontracted. The definition of the building strategy includes an estimate of the products or work packages that will be subcontracted during the project but subcontracting is also decided on the fly' to solve production problems that may arise. The system allows users to define work orders as subcontracted at any time (until actual hours are charged to the work order).

The issuing of subcontracted orders is similar to that of in-house orders, except that it is divided into several stages, due to the intervention of the purchasing department of the shipyard. The initial issue of a WO, with all technical details, is returned from the purchasing department with information regarding the external shop that has received the order, scheduled dates and contract cost. When the WO is completed and delivered back to the yard its status becomes "closed" and new information about delivery date, inspection or transportation costs, etc, is added.

Subcontracted work orders may be carried out in the external suppliers' shops or within the yard. In the former case, no hours are charged for shipyard services, such as movement or WO preparation, while in the latter case service hours are recorded and included in the cost of the WO.

Reports similar to those for in-house orders are available, plus some others regarding subcontractors by Processes or delivery schedule.

#### System Update Module

The main program of the module is a batch program that is run at the end of each accounting period. Its aim is

to keep the system abreast of actual costs incurred for tasks currently being executed. Actual labor cost retrieved from the standard personnel database of Shipyard. Daily information about the hours assigned every work order by every worker is stored in this database.

The system does not require a fixed length for accounting periods. Nonetheless it is customary for the shipyard to update the system weekly. Some shipyards make changes to the accounting periods in order to have information about complete months.

The main functions carried out by the update module are listed below.

- Integrity checking of the system that maybe carried out anytime interactively, allows users to analyze the files retrieved from the personnel database to find inconsistencies between these files and the system database
- Updating of the WO historical database with actual charged hours information for the latest accounting period;
- Apportionment of service hours to Work Orders currently being executed.
- Calculation of main values for each VIP during accounting period: Budgeted Cost of Work Schedule (BCWS), Budgeted cost of work Performed (BCWP), Actual Cost of work performed (ACWP) and Secondary Costs;
- Historical WP database update,
- Update of Cost performance Index (CPI) Value Estimates at Completion (EAC) for each WP in historical WP database,
- Update of historical databases for elements of the Project Work Breakdown Structure (PWBS), PBS and OBS hierarchies, and
- Revision and update of all historical databases, into account the subcontracting occurred during last accounting period.

The time taken to run the system update function depends largely on the amount of subcontracting during latest accounting period, because this variable requires revision of historical databases from the beginning of project. Once this revision is carried out the values of WP and for any given time reflect the latest known about the amount of work that has been subcontracted. Average updating time in an accounting period with subcontracting and about 1,500 work packages, 6,000 orders, with about 400 of them active is about 1/2 day. This timing has been obtained for the Production Control System running on a standard PC 486/66. Once the updating is over, reports are immediately available to anyone over the network. It is normal to have printed reports reflecting changes that have occurred up to 24 hours after updating.

## ASTILLEROS ESPAÑOLES S.A.

FACTORIA DE PUERTO REAL

SHIP #:

REPORT BY PBS  REPORT TYPE:

GROUP:

PROCESS:

TECH. FAMILY	BCWS	BCWP	SV	ACWP	CV	BAC	EAC	CPI	TCPI
01									
02									
03									
04									
NN									
TOTAL									

PROCESS:

TECH. FAMILY	BCWS	BCWP	SV	ACWP	CV	BAC	EAC	CPI	TCPI
01									
02									
03									
04									
NN									
TOTAL									

PROCESS:

TECH. FAMILY	BCWS	BCWP	SV	ACWP	CV	BAC	EAC	CPI	TCPI
01									
02									
03									
04									
NN									
TOTAL									

	BCWS	BCWP	SV	ACWP	CV	BAC	EAC	CPI	TCPI
TOTAL SELECTION									

PRODUCTION CONTROL SYSTEM

REPORT DATE: \_\_ / \_\_ / \_\_

DATA AS PER: \_\_ / \_\_ / \_\_

BCWS. BUDGET COST WORK SCHEDULED  
 BCWP. BUDGET COST WORK PERFORMED  
 SV. SCHEDULE VARIANCE  
 ACWP. ACTUAL COST WORK PERFORMED  
 CV. COST VARIANCE  
 BAC. BUDGET AT COMPLETE  
 EAC. ESTIMATE AT COMPLETION  
 CPI. COST PERFORMANCE INDEX  
 TCPI. TO COMPLETE PERFORMANCE INDEX

Figure 8. A sample of one accounting period report by process

### Reporting Module

The reporting module can produce simple and powerful reports that describe the state of a project at any level of detail. The operation of the module has been designed as user friendly as possible, for this is the only module used by most of the shops and production managers. The reports are offered in numerical and graphical form whenever possible.

Presently three types of reports are offered to users.

**Cost and schedule reports. (Figures 8 and 9).**

These reports allow a user a quick vision of the variables usual to CSC systems, as shown in the figures.

These values are shown for the last accounting period or for the last  $n$  periods, where  $n$  may be chosen by the user, with a maximum of 6 for reasons of space in the report (all of them are presented in A4 format). It is possible to obtain similar reports between two arbitrarily selected updating dates, grouping all the accounting periods between them. This utility allows users to analyze performance during a given period in a shop, for any desired process or interim product.



ASTILLEROS ESPAÑOLES S.A.										PRODUCTION CONTROL SYSTEM																																																	
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Figure 9. A sample of one accounting period report by organization

There is a degree of flexibility allowed to a user for customizing the report regarding the selection of the work packages whose values make up the report. The user is requested to decide the scope of the report using any combination of the elements of the Product Work Breakdown Structure, the Process Breakdown Structure and the Organizational Breakdown Structure. The selection process is organized using the hierarchical nature of these structures, and has been shown to be quickly comprehended by users with very little or no computer experience. It is very easy to select the information regarding the whole project, a shop, all activities of a production group, some processes carried out by a specified production group, a whole process, a product, or a combination of products of a certain level.

Graphic reports are offered, in addition to numerical ones, covering the evolution of BCWS, BCWP and ACWP from the beginning of the project. Also the evolution of CPI may be followed in a graph.

All reports are interactively obtained and may be followed on screen or copied on paper. Another property of the information obtained is that it is possible to obtain reports for any given accounting period not only for the current one. This possibility is explained by the exhaustive historical records that are kept for the state of the project any date since its beginning. The only difference that may be found between the report for a previous accounting period (obtained at the time of that period) and the same report obtained at a later date is that it incorporates all information regarding subcontracting that has been generated after the accounting period ended.

**Reports** may be obtained for in-house work, for sub-contracted work or for a limited combination of both. Also, in the case of in-house work, it may be desired to incorporate the service hours to the Budgeted Cost and to the Actual Cost of Work Performed, or to obtain a report showing only the direct costs, without services.

#### Productivity Reports.

It is possible to obtain at any time during a project or at its@ an estimate of the technical productivity rates that have been obtained during the project Productivities are derived statistically using as observations the actual man-hours spent in every finished WO included in the desired selection by Product or Organization.

The productivity is obtained for a single processor a range of processes, and its scope is determined by a selection process very similar to that outlined for the previous reports, but containing only the PBS and the OBS. For instance, it is easy to obtain the rates for welding thin or thick pipes (a uniquely determined process with two units of measurement), when this process is carried out by a specific production Unit or selecting some of the products that contain the process it is desired to analyze.

As the system keeps complete historical records of the evolution of the project, it is possible to ask for reports about the productivity rates at the end of any accounting period, not necessarily the last one.

Once the project is finished, the same module is used to compute statistical estimates of the productivity rates in terms of the parameters used in the first or second level definition of a project Those values may be used in figure estimation of workload.

#### Report of the Work Carried Out in a Period of Time

A functionality has been developed to obtain reports showing the hours charged during a certain period of time, selected by the user. The listings show how much effort has been dedicated during the selected period to a certain range of tasks. The information offered include the following

WOs that received any charges during the period scheduled and actual dates for these orders, man-hours charged during the period and accumulated status at the beginning and end of the period and cost and schedule variance

- Work packages acted upon during the period scheduled and actual dates for these packages, man-hours charged during the period and accumulated status at the beginning and end of the period percentage completed at beginning and end of period cost and schedule variance, and

Similar information is provided for products that have received charges during the period.

The range of information may be selected by a similar process to that described for previous reports.

#### Auxiliary Modules

There are a number of modules that are necessary for the operation of the system but add little from the theoretical point of view. Some of these are

- Utility for backing-up and restoring information based on those offered by the databases,
- Utility for initiating a database for a new project with partial copy from a previous project;
- Security system, based on personal and departmental keys for all functions of the system and an On-line Help system.

The simple enumeration of these systems makes clear their function.

#### SYSTEM IMPLEMENTATION PROCESS

At the beginning of 1993, the Technological Development Direction of the corporation was assigned the task of defining the theoretical basis of developing and implementing a production Control System. It was a condition of the system to agree entirely with the new concepts of construction by zones and stages and group technology, recently integrated into the production system of the shipyards owned by the corporation

The main aim of the assignment was to improve shipbuilding management within a larger program of increasing the shipyards competitiveness.

From January to June, 1993, all the theoretical bases of the System were developed as well as the basic decomposition structures. The work was jointly carried out by the Technological Development Direction and production teams from shipyards. One shipyard was chosen as the test facility.

The selected objective was the initial implementation of the system to control the building of a sophisticated 120,000 DWT shuttle tanker and a sister ship that was to follow. For this purpose, it was necessary to redefine the specification of the project according to the System theory, and accommodate all work packages and later work orders according to the same theory. A precondition of the work was to obtain all the information from the shipyard with the minimum disruption of the systems then being used at the time. The objective was met adequately.

The analysis and programming of the computer program that was meant as the system support was began simultaneously. A decision was made to produce the first implementation of the computer program on a PC. The idea was to use an inexpensive device, well known in the shipyards and user friendly, which could be easily extended through a local network. The program was developed in a

modular form as has been described. Milestones in its development and implementation were as shown in Table II

<b>Specification of the project and baseline analysis</b>	
Beginning	February, 1993
1st Operational Version	March, 1993
2nd Operational Version	June, 1993
<b>Cost and Variance Reporting</b>	
Beginning	May, 1993
1st Operational Version	September, 1993
2nd Operational Version	December, 1993
<b>Version 1.0:</b>	
1st Operational Version	March, 1994
2nd Operational Version	July, 1994
<b>Operational tests:</b>	
Initial tests	May - September, 1993
Pilot application	September, 1993-July, 1994

Table II: Implementation stages of the system

From March 1994, the system has been regularly applied and it has already been used for three new buildings, two shuttle tankers and a VLCC.

The system results are considered as official for control and personnel purposes in one of the shipyards since the beginning of September 1994 for steel processes and, from December 1994, for outfitting processes as well.

The conceptual basis and initial results of the system have been discussed with the managers from other corporate shipyards and the implementation schedule for these shipyards has started in September, 1994.

The productivity module, containing estimation for future construction is in the test period and will come into normal use by November 1994.

### Implementation

Implementation in the shipyard and real life application have not been an easy task. Even with the full cooperation of the production team, it was necessary to overcome a number of difficulties, such as noted below

#### Product Identification and Definition.

The factory already used a product catalogue in its production system. However, it was necessary to carry out a further *clarification* of existing products. The aim was to obtain suitable products for production control purposes, not too small for control operation, not too big and complex

for a meaningful contents definition. This is a continuing effort that is being improved from ship to ship.

#### Process Identification.

A similar task was the identification and normalization of processes, according to Group Technology theory.

#### Organization Definition.

Initially the existing organizational structure of the factory was left unchanged but experience in the system is providing clues for its improvement

#### Work documentation.

The previous work documentation system has had to be adapted to the requirements for the new Work orders. It is necessary to balance the need for more detailed documentation of the work orders to the shops with the increasing manpower required to prepare them.

#### Personnel Instruction.

Another worthy task has been to persuade all foremen and workers of the importance of a correct assignment. Time spent hours to the actual work order. The reliability of information is the cornerstone of the whole system of production monitoring.

This implementation process is being enhanced by the production of a System Manual. It contains the operational aspects of the system, as well as its influence over Production Organization. This manual will complement the program's User Manual, and on-line help.

### CONCLUSIONS AND PLANNED DEVELOPMENTS

According to expedience, the operation of the system, briefly described in this paper has two main advantages:

Swift and ad-hoc information thus improving managers' decision making and corrective actions, based on accurate and timely information.  
Superior capacity for the analysis of efficiency in the various shops, processes and products.

This situation increases managers' capabilities to promote improvements in productivity and more accurate estimates for future projects. In short the System helps foresee situations and problems, increasing the competence of the shipyards.

A number of improvements and extensions are planned for the described Production Control System;

- Improved connection to Planning Systems.
- Full development and use of the Product concept Integration of materials in the Control System.
- Development of an object repository for connection with CAD systems and Production Engineering.
- Development of a graphical deviation analysis module.
- Development of a module for the simulation of production decisions.

The Production Control System is meant to be a useful element in the planned Computer Integrated Manufacturing System envisioned as necessary to keep yards competitive in the global shipbuilding market

#### ACKNOWLEDGMENTS

The authors would like to show their acknowledgment to Mr John J. Dougherty for work and continuous advice during the time of the System basic development.

During the preliminary stages of this project, contact Was established With Other advanced Shipyards, especially Saint John Shipbuilding Ltd, which gave us important ideas and suggestions in the way to translate the very sophisticated Cost, Schedule and Control systems to this Production Control Systems more adequate for a commercial shipbuilding program.

Last but not least the authors thank the great efforts of the cooperating production teams in the test shipyard, who have passed along gladly their experience and have suffered all our mistakes.

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**THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS**  
**601 PAVONIA AVENUE, JERSEY CITY, NJ 07306**

Paper presented at the 1995 Ship Production Symposium  
Westin Hotel, Seattle, Washington, January 25-27, 1995

**A Comparative Study of U.S. and Foreign Naval Acquisition,  
Design and Construction Policy and Practices**

Patrick D. Cahill (AM) and Howard M. Bunch (LFL), University of Michigan Department of  
Naval Architecture and Marine Engineering, U.S.A.

**ABSTRACT**

In an effort to reduce the cost of Navy ships without significantly reducing capability, the U.S. Navy has performed a series of ongoing investigations into areas of potential cost reduction. One of these investigations was a literature study done at the University of Michigan Department of Naval Architecture and Marine Engineering to identify and compare acquisition, design and construction practices in a number of different countries. Recommendations for potential cost saving changes to the U.S. Navy system including reduction of administrative costs, design to cost, and changes in labor policies, were made based on the comparisons. This paper is a modified version of the final report submitted to the Department of the Navy.

**INTRODUCTION**

The United States Navy operates some of the most sophisticated and technologically advanced ships in the world. In order to perform the primary mission of maintaining U.S. sovereignty as a maritime nation and freedom of the seas, the Navy must be prepared to meet a spectrum of threats from simple to highly advanced anywhere in the world at any time. To ensure that Naval Commanders always have a technological edge over any threat, the Navy has evolved a complex infrastructure for ship design and acquisition. Historically, performance factors have always had precedence over cost factors. However, now and into the foreseeable future, cost is increasingly important.

Rather than reducing the capabilities of its ships, the Navy is interested in reducing costs by adopting more efficient practices in the acquisition, design and construction processes. The perception that there is room for improvement was highlighted by a March 1993 visit by NavSea personnel to Japan, where it was noted that the Japanese IHI shipyard in Tokyo expects to build DD 176 (Hull 2316), the fourth ship of the Kongo class Aegis destroyers, for 2-2.2 million man-hours. This will be the first of the class to be constructed in Tokyo, the first three will be built at MHI

in Nagasaki. (Summers, 1993) This is compared to the construction man-hours on the DDG-51 class, which range from 4.5-5 million man-hours for DDG-51 to 2.5-3 million man-hours on DDG-56, BIW's fourth of the class. The reasons for fewer man-hours in Japan are numerous, including increasing dimensions to allow easier construction access, use of commercial grade equipment, and a different design and construction process. (summers, 1993)

This paper outlines the significant phases in the naval acquisition design and construction process for a number of different countries, and attempts to relate them to the equivalent U.S. Navy phase. Comparisons of time to completion, cost level of detail and end products of each phase were developed using information available in the University of Michigan and NavSea databases. Areas for potential improvement within the U.S. system are also identified.

The major broad areas for improvement detailed in the body of report, are: reduction of administrative costs by the government; adopting a design-to-cost system, using concept design to drive R&D efforts incorporating build strategy and lifecycle cost analysis into early stage design, adopting some basic paradigm shifts in the understanding of the relationships between, cost, dimensions, weight system complexity and producibility; and development of more efficient labor practices within the private shipyards.

**OVERVIEW OF THE NAVAL ACQUISITION,  
DESIGN AND CONSTRUCTION PROCESS**

This section provides a brief overview of the process and major organizations involved in each country reviews and includes some nations for which very limited data was available and are therefore not expanded in the body of the report.

**US. Navy**

The United States Navy uses a phased process in which a design typically matures within the Navy, and budgeting approval is provided through a civilian/military interchange. Designs are primarily government generated through contract design, at which

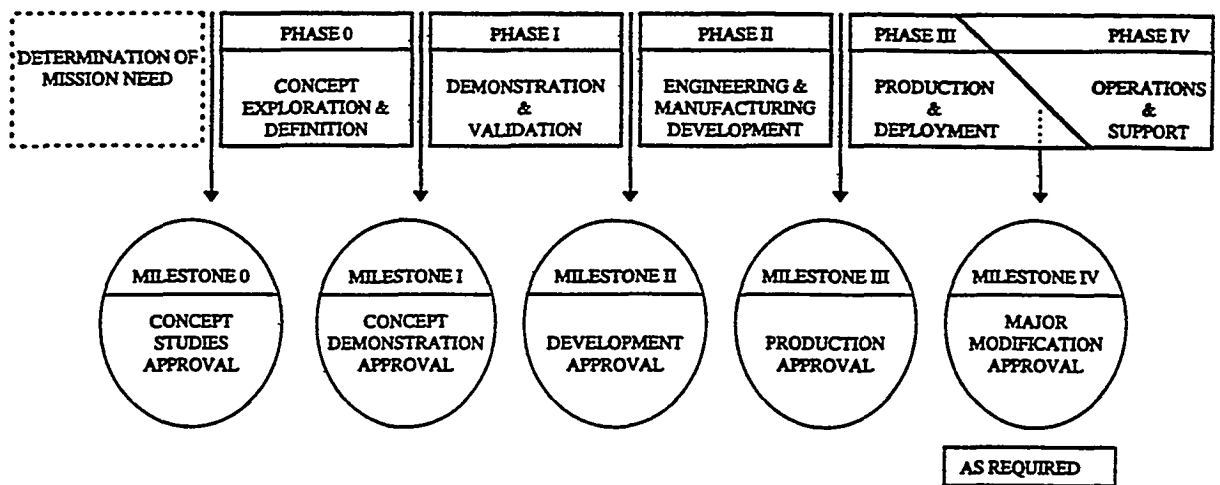


Figure 1 USN Acquisition Process (Ball, 1992)

time bids are taken from private shipyards, who perform both detail design and construction. Government interaction continues throughout construction, and many changes are incorporated as construction progresses. In 1993 the Navy underwent major organizational changes that have impacted the details of the procurement process. The basic process, which is derived from the Department of Defense (DOD) 5000 series instructions, is unchanged and is shown above in Figure 1

#### Japan

The *Japanese* government uses a phased process similar to the U.S., but with considerably fewer players. Designs are developed through contract design by the government. Construction contracts are generally not competitively bid. Private shipyards perform detailed design and construction with very little government interaction and few changes to the design during construction. **Figure 2** shows the basic process and

EXECUTOR	MARITIME STAFF OFFICE	INTERNAL BUREAU OF THE JAPAN DEFENSE AGENCY	MINISTRY OF FINANCE	DIET
ITEM	REQUEST → (MSO PLAN)	REQUEST → (JDA PLAN)	GOVERNMENT PLAN →	APPROVAL
SCHEDULE	April	August	December	March

Figure 2 Process of Budget Request (JDA, 1993)

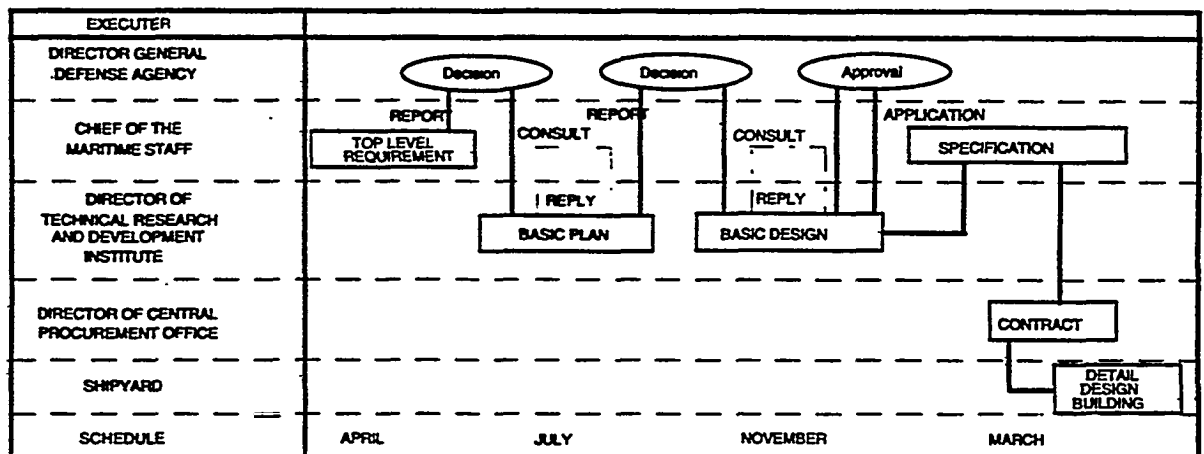


Figure 3 Process of Naval Shipbuilding (JDA, 1993)

organizations involved, while Figure 3 lays out the major milestones and the decision making process.

#### Italy

The entire process is closely controlled within the Navy, and parallels the U.S. process. Contracts are competitively awarded to private shipyards, who do detail design and construction. The Italians may also use government shipyards for construction, rather than strictly private firms. (Craig, 1993)

#### Germany

The phased process is again similar to the U.S. It is notable that a civilian design firm is brought in early to review the military developed concept and provide feedback as on how well the design concept addresses the requirements. (Abels, 1992)

#### Korea

Due to the high degree of government involvement

in their commercial ship construction, the military process is believed to be closely government controlled, with the detailed design and construction performed by private yards. (Martin, 1990)

#### Canada

The Canadian (and NATO) processes are very similar to the U.S. process. A significant difference is the design-t-cost philosophy adopted in the earliest stages of design. Contracts are competed to private yards for detail design and construction. Figure 4 illustrates the Defence Program Management System (DPMS) process, while figure 5 shows the relationship of the process to design progress. (Craig, 1993)

#### NATO

NATO has a Periodic Armament Procurement System (PAPS) similar to the Canadian's DPMS. The NATO process is shown in Figure 6.

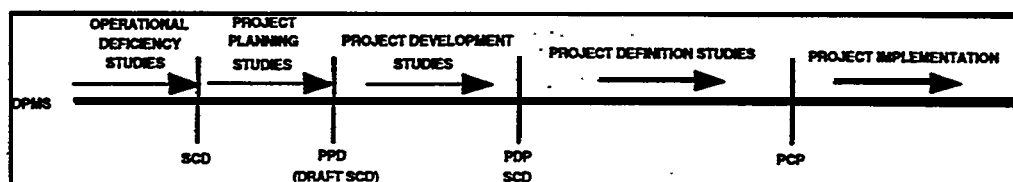


Figure 4 DPMS Process (Craig, 1993)

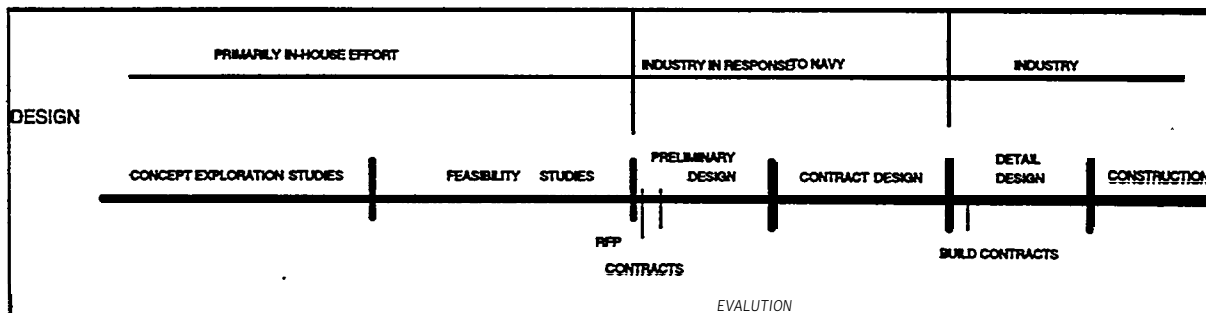


Figure 5 Canadian Design Recess (Craig, 1993)

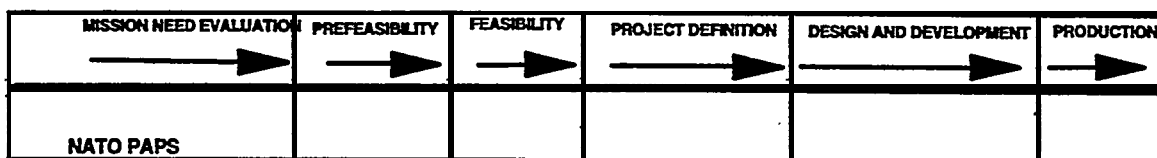


Figure 6 NATO PAPS process (Craig, 1993)



## U.K

The British system is also similar to the U.S. process in terms of phases and end products of each phase. Design through to the contract stage is performed primarily by the Navy, with detail design and construction contracted out to private yards. A major difference appears to be in the emphasis on driving research and development efforts from warship design concepts, rather than trying to fit a research and development (R&D) product into a maturing design. This is elaborated on in the following section. (Andrews, 1992)

## France

The French process is quite different from the U.S. process in that the government through the Director of Naval Construction, exercises control for the entire life of the project from concept through construction. The detailed design and construction are done by a government shipyard, and there is no competitive bidding involved. (Andrews, 1992)

## PROAPPROVAL AND CONCEPT DEVELOPMENT PHASE

## U.S. NAVY

The acquisition process currently in effect for major warships is Acquisition Category I-D (ACAT ID), in which the Secretary of Defense is the major milestone decision making authority. The basic flow for the process is shown below in Figure 7.

A brief explanation of the abbreviations used is provided in Table I below. The process starts when it is determined that a capability shortfall exists which generates a need for a new ship. The most common reason for the need is to replace a ship class that is leaving service because of old age, inability to modernize or excessive cost of operations and maintenance. For many years, force levels were held relatively constant which generated the need for replacement. Although force levels are being reduced, replacement is still the number one reason for new ship designs. Other reasons for new ship designs include

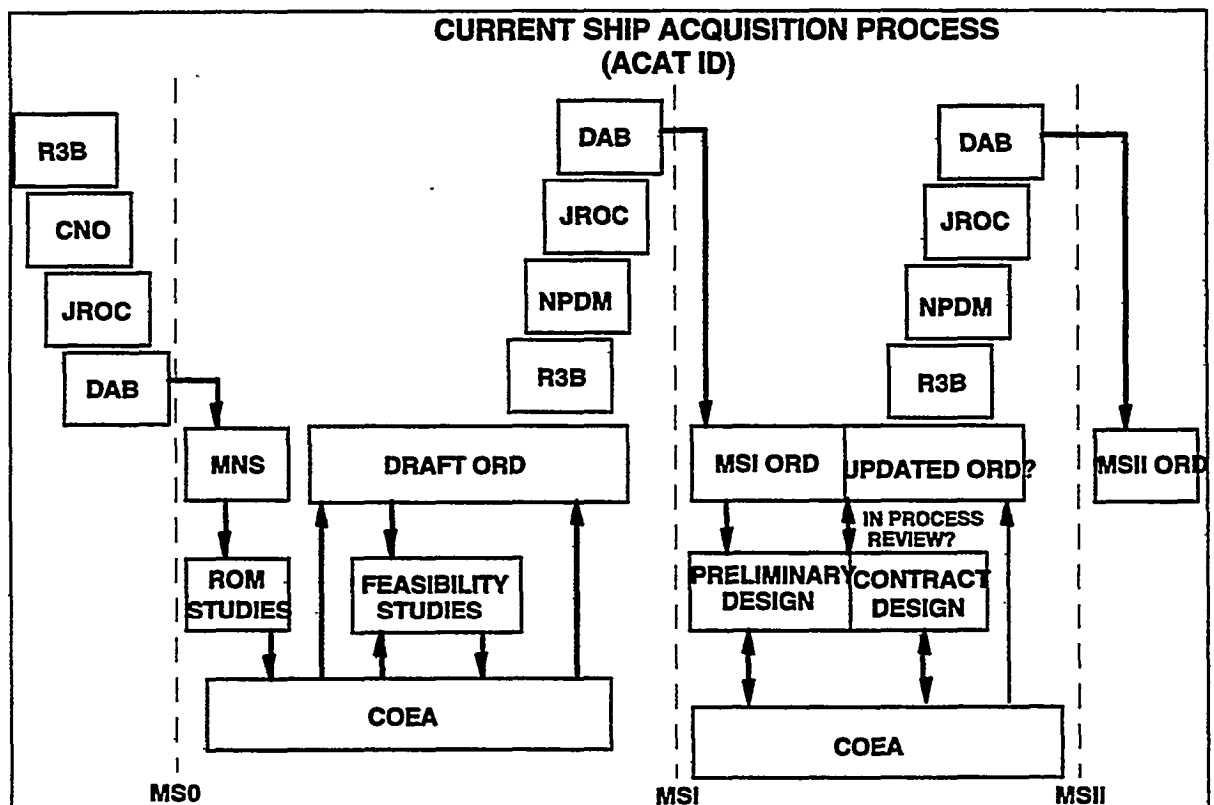


Figure 7 ACAT ID Process

R3B	Resources Review and Requirements Board, Chaired by N8
CNO	Chief of Naval Operations
JROC	Joint Requirements Oversight Council, includes all service vice chiefs and the Assistant Commandant of the Marine Corps
DAB	Defense Acquisition Board chaired by the Undersecretary of Defense (Acquisition)
NPDM	Navy Program Decision meeting
COEA	Cost and Operational Effectiveness Analysis
ORD	Operational Requirements Document
MNS	Mission Need Statement

Table I (Tibbits, 1993)

new threats (Aegis ships in response to new air to surface and cruise missile threats), new or changed missions (the driver behind the development of the mine countermeasures support ship) and new technologies (SWATH and LCAC's). (Tibbits, 1993)

The ACAT ID process formalizes the pre-milestone O decision making, and requires the involvement of a number of different organization. They generate a Mission Need Statement (MNS) which is limited to three pages in length and states the need that must be satisfied, but does not address performance requirements or solutions. The MNS is then forwarded for both Joint Chiefs of Staff (JCS) and DOD approval. After approval, feasibility design studies begin, but the new process adds an iterative cycle of Cost and Operational Effectiveness Analysis (COEA) into the studies at both a Rough Order of Magnitude (ROM) and feasibility design level of detail. The COEA results in the inclusion of performance objectives and thresholds in the Operational Requirements Document (ORD), which has replaced the old Tentative Operational Requirements (TOR) document. In fact, the COEA is now required at every phase of the design process and must be done at each subsequent milestone following milestone O. The entire process up to milestone O can take 1-3 years. (Tibbits, 1993)

#### Japan

The Central Procurement Office (CPO) is the organization authorized by the Director General of the Japan Defense Agency (JDA) to procure major defense articles and services. (Grossi, 1993) The JDA does not have to undergo the same procurement process as the

**U.S.** A block funding method is which in which the CPO decides what to buy based on a long term defense plan, and authorizes design development and procurements. The JDA budget is approximately \$30 billion, of which five percent or \$1.5 billion is dedicated to ship construction. This \$1.5 billion annually is budgeted out to provide for the construction of approximately five naval vessels per year two major combatants, one auxiliary, one mine warfare vessel and one submarine. The goal is to maintain a fleet of approximately 60 ships. (Martin 1990)

#### Italy

The concept development stage is called Phase O in the Italian process The primary inputs. are mission analysis and long term forecasting which define the Long Term ten-year planning. The Plan and Policy (3rd) Department and General Financial Planning Office of the Navy General Staff are the major players in this phase. (Craig, 1993)

#### Germany

The German Navy determines the operational requirements for a new vessel. This phase is not considered as part of the formal design and construction cycle. (Abels, 1992)

#### Canada

The Canadian DPMS closely follows the U.S. system in terms of phases of Naval acquisition, design and construction.

The DPMS initial phase is actually broken into two parts, referred to as Operational Deficiency Studies and Project Planning Studies. This phase defines the operational requirements and specific concept alternatives (with costs) to meet the requirements. (Craig, 1993)

#### NATO

The NATO Periodic Armaments Procurement System (PAPS) also closely follows the U.S. process. The first phase of the NATO PAPS is Concept Exploration Studies. (Craig, 1993)

#### U.K

The Royal Navy process combines the two phases of concept Studies and Concept Design. Concept Studies are usually commenced ahead of a clear requirement and are closely linked to weapons systems proposals and development commenced sufficiently early, they can be used to identify where research and development efforts should focus. (Andrews, 1992)

Concept Design occurs about 10 years prior to the First of Class In Service Date, and marks the beginning of the approval process for the Staff Target and Staff

**Requirement** The production of a baseline Concept Design sufficiently defined to be costed with some accuracy is more important than the range of material solutions, since it provides the basis for investigating incremental capability enhancements. It is complemented by Operational Research studies, on either whole ship characteristics or aspects related to major weapon system choices. From these studies, the staff develops the staff target and provides a paper to the Equipment Procurement Committee (EPC), whose agreement is required to commence feasibility. (Andrews, 1992)

The process takes 1-3 years to complete and is performed within the Defence department. Multi-level departmental endorsements are required throughout the Ministry Of Defence. The papers are continually updated and revised, as special interests are allowed to suggest and add features to the ship concept. (Andrews, 1992)

#### Comparison

The U.S. process is very involved, and requires the participation of a number of different organizations and individuals. However, many of the other countries reviewed use a similar process. The most notable exception is the Japanese block funding process, which eliminates several iterations of the acquisition cycle.

The complexity of the pre-approval process may have the positive effect of exercising greater control over Naval acquisition by ensuring a well developed set of requirements, but adds time and, therefore, cost to the process. Longer term, dedicated budgets, such as used by the Japanese, may help eliminate some of the "red tape" in the U.S. process. However, a long term budgeting process has the downside of limited flexibility in responding to changing requirements.

Additionally, the U.K process of closely linking ship concept development to systems R&D would appear to be a cost effective practice, providing distinct and specific guidance to R&D efforts, which then reduce later design costs as a more mature system or concept is placed on the ship.

## FEASIBILITY STUDIES

### U.S. Navy

Feasibility studies begin at Milestone O, and are performed by teams of 3-20 dedicated engineers, with additional technical and subcontracting support brought in as needed. The primary purpose of a feasibility study is to produce cost schedule and performance alternatives to help the ultimate customer (CNO) decide what he will buy. If the cost estimate is to be credible, the feasibility study team (typically less than a half

dozen design engineers working for several weeks to several months) must produce a ship design which accurately predicts what the ship will look like at the end of contract design 18-36 months later. This requires an intimate knowledge of the myriad of NavSea design practices and standards and the NavSea/DTRC developed computer synthesis models. Engineers with such experience are rare (even in the Navy), which is the major reason why correcting out early stage design is fraught with risk. There are, however, instances where the design workload is such that additional resources are needed, and a few feasibility studies are contracted to selected naval architecture firms. (Tibbbs, 1988)

The primary objectives of feasibility studies are to:

- Determine cost and performance alternatives that allow the decision makers to assess cost versus capability,

- Identify feasible solutions,

- Address major technical risks, and

- Provide class F cost estimate (not of budget quality).

A feasible design must meet four criteria; it must meet the need, be affordable from a Ship Construction New (SCN) standpoint, be technically executable from an engineering standpoint, and be politically acceptable. The final package of a feasibility study is a set of drawings, sketches and documents that contain a:

- Description of the ship geometry;

- Definition of all mission critical subsystems;

- Definition of areas and volumes in a general arrangement drawing and

- Single digit weight estimate by Ship Work Breakdown Structure (SWBS), which is the primary input to cost estimates.

Feasibility studies can be accomplished in 316 months. However, the review process and COEA can add another six months to the process. (Tibbbs, 1993)

During this phase the NavSea Shipbuilding Support Office (NAVSHIPSO) provides Advanced Planning Studies (APS) to the Ship Acquisition Program Manager (SHAPM), which provides estimates of required contract and construction periods, manning level requirements and production need requirements of principal long lead components and controlling items. (Ennis, 1991).

### Japan

In Japan the feasibility study phase takes approximately 2 years. Included are combat system integration studies, arrangement studies, support systems studies, electric plant and damage control studies. The time and cost to complete the process is difficult to determine, as the Japanese actually

Performed pre-studies of the DDG-51 and built mock-ups of the SPY-1D array for the DD 173 beginning three years prior to budget approval. (Summers, 1993) Further research would be required to determine if other Japanese naval construction programs also used a pre-study pm.

#### Italy

The feasibility phase is called Phase 1 in the Italian process. The goal is to produce the staff requirement. In this phase a rough operational requirement is generated by the planning and policy department for the requirements department. The requirements department is composed of approximately 40 operational officers from the various combat areas (Weapons, Communications, Command and Control Systems, ASW, etc.), Engine Plants and Platform officers. This department is responsible for the refinement of the operational requirement which is then forwarded to the "design committee", MARICONAVARMI and to the procurement agency, the General Directorate for Shipbuilding and Naval weapons systems, NAVALCOSTARMI. MARICONAVARMI is tasked to provide technical support to the Navy General Staff, and conducts a feasibility study based on the operational requirement. NAVALCOSTARMI develops a first estimation of costs. After a final review, which includes cost capability trade off analysis, the Operational Requirement is endorsed at the General Staff level and used as the basis for Phase 2. (Craig, 1993)

#### Germany

Feasibility studies are called the Pre-Concept phase in the German design process. It involves the Navy definition of requirements and a private design firm's analysis of those requirements towards the development of a design. The end product of this phase is called the tactical requirement. (Abels, 1992)

#### Canada

In the DPMS this phase is referred to as Project Development Studies. The objective is to develop the technical baseline of the design and provide a level of detail sufficient for a preliminary cost estimate, which is the basis for a design to cost target. This phase determines the "maximums" for a design. All subsequent phases, in theory, only reduce size, weight and cost. (Craig, 1993)

#### NATO

This phase is broken into two parts in the PAPS: Preliminary and Feasibility. The goals, objectives and outcomes are the same as in the Canadian system. (Craig, 1993)

#### U K

This phase is also referred to as Feasibility Studies in the Royal Navy. They are conducted by a full pledged Project team under the leadership of a Warship Project Manager, which is similar to the U.S. SHAPM. These studies provide the technical justification behind submission to the Equipment Procurement Committee of the more substantial Staff Requirement. They also explore the viability of the requirement and provide a clear cost. This is followed by Ministerial approval for expenditure of the next phase. (Andrews, 1992)

Subcontracting to industry and design firms is occasionally undertaken during feasibility studies. This phase typically lasts 1-2 years and requires at least 30 man years of effort. (Andrews, 1992)

#### Comparison

Information available shows that the feasibility study process is approximately the same in all countries reviewed, with roughly the same end product; a tactical requirement that defines the basic parameters of the ship. It is interesting to note that in the Canadian and NATO systems the resultant design is considered to be a maximum and provides the basis for design-to-cost limits. This may be a good model for the U.S. to follow, as it determines at a very early stage what capability can be purchased for a given budget and drives all later design parameters.

Although specific cost information for comparison is not available, it is apparent that the Japanese system of performing pre-studies and other design activities prior to budget approval for a specific vessel may result in the appearance of a less expensive design process.

It is also notable that the Germans bring a civilian firm into the process very early to determine whether or not the Navy developed design is actually feasible and meets the desired requirements.. This may be of use to the U.S. Navy, as many of the design firms in Washington are filled with former military personnel with considerable experience that could be applied in an early stage design review.

#### PRELIMINARY DESIGN AND CONTRACT DESIGN

##### U.S. Navy

preliminary design starts at Milestone 1 and includes preliminary hull, mechanical and electrical (HM&E) design, combat systems integration worth and continued program documentation development by the SHAPM. (NavSea 1990)

During this stage, firm "design to" requirements, budgets and constraints are established. Numerous

tradeoffs are conducted at the subsystem and component levels, and synergistic combinations are sought. Preliminary design is much more labor intensive than feasibility studies (several hundred engineers working for a minimum of six months) and considerable numbers of individual tasks are contracted out (Tibbits, 1988)

The trend towards increasing reliance on contractor support continues. For the more typical design where the Navy retains firm hands-on control, more and more tasks are being contracted-out by individual technical codes. A 1982 ship design study acknowledged this to be a permanent way of life and recommended various steps be taken to improve the process. As a result long-term contracts were competitively awarded to a pair of contractors for whole ship design support. Pairs of contracts were also awarded in support of each major engineering group and subgroup. (Tibbits, 1988)

During this phase of recent Naval designs the Navy has also involved shipbuilders as a group. The shipbuilders have generally only provided producibility recommendations, which has been expanded in recent designs to include preliminary build strategies.

At the end of the preliminary design stage a cost estimate is developed which is based on the parameters defined by the design. The primary parameters are weight and dimensions, which are used as inputs to the Navy's computerized cost estimating models. Producibility is not accounted for in the cost models developed by NavSea with the result that complexity and system density can eventually add to the original estimated cost.

To change the ship costing models so that each specific volume type would have its own systems cost (tanks cheap, electronics costly in terms of supporting systems) and so that **deck height reductions would raise rather lower costs would require major investments in time and money.** (Sims, 1991) This is an area that the Navy is currently working to improve.

The entire process lasts 6 months to a year. and, prior to the ACAT ID process, resulted in the Top Level Requirements, which is the minimum specifications. It includes a hullform and preliminary definition of all HM&E and Combat Systems components necessary to meet the TLR. Specifically, the preliminary design includes

- More detailed ship geometry;
- Three digit SWBS weight estimate which allows generation of a Class C, or budget quality cost estimated
- **Ships lines** and arrangements drawings;
- Master Equipment List (MEL);
- Intact and damaged stability analysis; and
- Combat system baseline.

## Japan

**It is** during the preliminary design phase that one of the major differences in the Japanese process, the use of concurrent design becomes apparent. Concurrent design is a highly leveraged concept and associated body of practice to simultaneously design a product and its associated life cycle processes. For the Defense Industrial base it holds the potential for producing products that better satisfy end user needs and substantially reduce acquisition cost and development time. It can also ensure the availability of appropriate manufacturing means for manufacture of advanced weapon systems, and replace inefficient sequential design practices which prematurely narrow design options. Concurrent design results in streamlined practices in which non-value added labor is reduced more design options are kept open longer, and issues of performance, Producibility, supportability, quality and cost are simultaneously considered and traded off from the earliest phases of design. (Martin, 1990)

The preliminary design stage for the DD 173 lasted approximately 6 months. (Summers, 1993)

## Italy

This phase, called Phase 2, details the Technical-Operational requirements of the project. It involves iterations through the General Staff, MARICONAVARMI and NAVALCOSTARML. The output of the phase is a General Rejection Document that covers all aspects of the design, including life cycle costs, and is submitted to the Chief of Naval Staff for approval. (Craig, 1993)

## Germany

Called Concept Phase in German design. It includes a complete preliminary design, selection of all major components, and start of support planning by the design agent. The construction yard begins build strategy development and cost estimating. The Navy shifts to an approval role during this phase. (Abels, 1992)

The end product of this phase is called the Military-Technical Objective, similar to the TLR or ORD.

## Canada

This phase is referred to as Project Definition Studies in the DPMS. It actually encompasses the equivalent of preliminary and contract design in the U.S. process. The objective is to provide a functional baseline for the detailed design, with functional descriptions of all systems and their integration. Specific design characteristics are also identified and written into the specifications, such as noise, EMI, shock and other requirements. (Craig, 1993)

## NATO

Also referred to as Project Definition, but does not include the contract design phase. The objectives are similar to the DPMS, but does not include detail enough for writing specifications. (Craig, 1993)

## U.K

This phase is referred to as Design Definition in the U.K and involves both preliminary design and contract design. The design is expanded from several options, each having a general arrangement and roughly 10 critical system drawings, to a single option, the ship definition, encompassing over 200 contract guidance drawings. (Andrews, 1992)

The effort requires 1-3 years to complete. (Andrews, 1992)

## Comparison

Again the phase and its objectives are similar for all nations reviewed. However, two major activities begin in other countries that did not formerly occur in the U.S. process. These are the development of life cycle costs and the beginning of a build strategy. Both of these activities, occurring during preliminary design, will have the effect of reducing costs during detail design and construction. Part of life cycle cost development is the definition of logistic support requirements, which, in order to reduce costs over the entire fleet, dictate commonality in systems and components. The development of a build strategy during this early phase results in producibility driven design concepts being incorporated into the next phase, contract design. The LPD-17 design will be the first major naval vessel to be designed under the ACAT ID process, which incorporates the COEA. This new process should address many of the concurrent engineering deficiencies in the U.S. Navy.

## CONTRACT DESIGN

### U.S. Navy

In the former acquisition system the preliminary design package went into contract design following another Ship Characteristics Improvement Board (SCIB) review, with the same organizations playing key roles. In the new System, there is no milestone separating preliminary and contract design. In contract design the size of the team is doubled, and an effort of about one year commences. (Tibbits, 1993)

Participation in contract design has varied over several U.S. Navy programs. In the DDG-51 design the Navy retained contract design in-house, but selected three shipbuilders to participate in the design. In the

SSN-21 design, the contract design was contracted out to the two shipbuilders, who had both participated in preliminary design. The LHD and LSIM1 contract designs were also contracted out to shipbuilders. (Tibbits, 1988)

The end of contract design results in a package of contract drawings, contract guidance drawings, Project Peculiar Documents (PPD's) and specifications of sufficient level of detail to allow a shipbuilder to develop a bid. These generally include ship's lines drawing, combat systems space and wiring arrangement drawings, main and auxiliary machinery space and system arrangement drawings and detailed specifications. (NavSea 1990) In addition, Government Furnished information and material (GFI and GFM) schedules are developed, the Contract Data Requirements List (CDRL) is generated, the HVAC manual is written and an electric load analysis is performed. (Tibbits, 1993)

Cost Modeling. Contract design is the point at which weight dimensions and acquisition cost estimates are frozen. Decisions made up to this point have a lasting impact on the acquisition cost of a ship class. The DDG-51 lead ship cost was severely impacted by decisions made up to and including the contract design stage, as evidenced by the number and scope of Engineering Change Proposals (ECP's) and Field Modification requests (FMR's) incorporated into the design during construction.

The most significant of these decisions was relating cost directly to weight, ignoring the producibility cost impacts of compressing systems and equipment into a smaller volume. The DDG-51 design team was under extreme pressure to reduce cost. Because of the perceived relationship between cost and weight the beam was reduced by 2 feet under direct orders from the Secretary of the Navy (SecNav), and the clean ballast fuel system was replaced by a more complex and expensive compensated fuel system. The U.S. Navy is slowly learning that low cost and ease of construction are often inversely related to dimensions and weight. (Sims, 1991)

Contract vs. Guidance Documentation. The U.S. Navy has historically issued contract versus guidance drawings for a number of systems and spaces. The difference is that the locations and arrangements defined in the contract drawings are legally binding to the shipbuilder, and can only be changed through a formal change process. On the other hand contract guidance drawings provide a recommendation for locations and arrangements, and the shipbuilder is given latitude to make minor changes in order to accommodate production efficiency.

**Preparation of specifications.** Detailed specifications are written by individual NavSea technical codes and compiled by the SHAPM. Literally hundreds of personnel are involved in the development of a set of ship's specifications. The General Specifications (Gen Specs) are used as a baseline, and modified to suit the changes incorporated by the individual whicrd codes. The technical codes do not always coordinate their specific changes with each other, resulting in a specifications package with a considerable number of conflicts, which results in confusion and changes in the shipyard. (Ball, 1992)

It should be noted that the design practices of the U.S. are more thoroughly documented than those of other nations. (Tibbits, 1988)

#### Japan

The Japanese equivalent of Contract Design takes approximately 6 months. However, it differs in its intensity and need for detail because contracts are not competed in the Japanese system. (Summers, 1993) It is performed by government designers who are employed by Defence Ship Design Department (Grossi, 1993)

It is apparent that in the Kongo design, the Japanese, with the help of engineers who worked on the DDG-51 design have learned from the mistakes made on the DDG-51 class. The U.S. Navy sent a Naval Architect to Japan, who assisted in designing a ship with an optimized size to displacement ratio. This resulted in a design with increased overall dimensions and deck heights in order, to avoid the construction congestion problems experienced on the Arleigh Burke. (Sims, 1991)

#### Italy

Phase 3 is similar to contract design, during which NAVALCOSTARMI develops and issues the technical specifications. (Craig, 1993)

#### Germany

Called Definition Phase in German naval design. It includes development of a 1:5 scale basic model and the specification package. Navy preliminary approval of the specification occurs during this phase. The shipyard will begin contract negotiations at the end of the phase. (Abels, 1992)

#### Canada

The contract design phase is incorporated into the Project Definition Studies phase. The contractual package is similar to the U.S., with a set of

specifications and contract drawings developed. (Craig 1993)

#### NATO

The contract design stage is incorporated a phase called Design and development which includes the beginning of Detailed Design. The final product is a contractual baseline and a level of definition adequate for a Class B cost estimate, which is the design-to estimate. (Craig, 1993)

#### U.K

Contract design is incorporated into the Design Definition phase. It should be noted that guidance rather than contract drawings are developed. (Andrews, 1992)

#### Comparison

Contract design is very similar in most of the nations reviewed. The level of detail generated by the U.S. Navy and some other countries is much greater than that developed in Japan. This is directly related to competition for contracts. The only other notable difference is the German development of a 1:5 scale model during contract design which the U.S. Navy is beginning to do through three dimensional "virtual CAD models.

#### PRE-AWARD PHASE

##### U.S. Navy

The pre-award phase begins at Milestone 2, following Defense Acquisition Board (DAB) approval of the contract design. This phase involves development of the Request for Proposals (RET) by the SHAPM. The RFP is the compilation of the contract design, specifications and Contract Requirements Documentation List (CDRL). (Tibbits, 1993) The RFP is presented to DoD, and then released to the shipbuilders for bids. During this phase the shipbuilders develop a build strategy to support their bid, and are provided an opportunity to request clarification of the REP. The end of this phase results in a contract award, and the start of detail design. The total time for this phase is approximately one year. (NavSea 1990)

Competition and Multi-sourcing vs. Non-Competitive Awards. The US Congress requires that the Navy compete the award of new construction contracts between at least two shipbuilders. However, competition continues to be a gray area. Newport News

is the only shipyard capable of building nuclear aircraft carriers, while Newport News and Electric Boat Groton are the only private yards capable of building nuclear submarines. Public yards, such as Portsmouth, N.H., have essentially been dropped out of the equation. Aegis ship construction is currently restricted between two Aegis qualified yards, Bath Iron Works and Ingalls. The conclusion that can be drawn is that although competition occurs, it is restricted competition, and multi-sourcing often means dual sourcing.

#### Japan

The time for the pre-award phase is approximately 8 months. The shipbuilding contracts are not competitively bid. (Summers, 1993)

#### Italy

This is Phase 4, during which NAVALCOSTARMI activates the administrative procedures, including the choice of contractual procedures. The Phase ends with the signing of contracts. (Craig, 1993)

#### U.K

**Requires** approximately 1 year for contract negotiations to be completed. (Andrews, 1992)

#### Comparison

It is during this stage that build strategies are developed within the shipyards and used to support a bid. The contract package has already been developed and changes to suit production methods are difficult to incorporate. The result is that the shipyard must develop a build strategy to suit the design, rather than bid on a design that has already incorporated a logical build strategy.

#### DETAIL DESIGN

##### U.S. Navy

Detail design begins at the winning shipyard as soon as a contract is awarded. The initial phases of detail design include procurement of government furnished equipment (GFE) by the government, integration of combat systems software, production planning, structural design and systems design. Detail design overlaps with construction, and is normally about one year ahead of construction. (NavSea 1990)

The total time for detail design is approximately 2 years. (Tibbits, 1993)

The detailed design of the DDG-51 required the services of over 2000 engineers and designers from Bath Iron Works and Gibbs and Cox.

Navy participation continues into the detail design phase. Today, ship design teams continue in being, albeit at reduced levels, past the completion of the contract design phase for all combatant ships and selected auxiliaries and amphibious ships. There is active participation at design reviews with the shipbuilder during the detail design and construction phase. In addition there is a heavy workload associated with the review or approval of shipbuilder drawings, purchase orders, design studies and other key technical documents. (Tibbits, 1988)

**Level of Detail Detail .Detail design of modern Naval ships** includes production design and engineering. Modern Naval design incorporates zone design to allow for group technology construction. Composite drawings that incorporate all structure, equipment and systems within in a zone are developed for interference checking. In the past the composites have been two dimensional overlays, with a separate overlay for each design discipline and major system group. Recent designs have incorporated three dimensional computer generated models, which have greatly enhanced the accuracy of design. In addition to the composites, separate system and arrangements drawings are developed for each system and equipment group (arranged by product Work Breakdown structure (PWBS)). From these detailed zone drawings a series of production drawings that details the fabrication of piece-parts are developed and provided to the production workers. In addition to the drawings, a computerized parts and inventory list is developed. Finally, a detailed production plan, specifying time, order and location of all components is prepared.

In the U.S., very few full scale mock-ups are built as construction aids, something that was emphasized in the Japanese Aegis destroyer program.

Part of detail design is the development of documentation to fulfill the CDRL'S or Contract Drawing Requirements Listt which are the portions of the detail design submitted to the Navy for review and/or approval. Table II is a list of typical detail design documents generated by the shipbuilder and reviewed by NavSea.

**Change Order Process.** The US Navy has historically relied on the change order process to correct design deficiencies, incorporate in-process shipbuilder recommendations for improvement and incorporate system and equipment updates and improvements. Modern Naval construction requires a shipyard to have an entire division of engineers and designers dedicated to the Engineering Change Proposal (ECP) process.



A.	Purchase Specifications
B.	Technical Manuals
C.	Equipment Drawings
D.	Test Plans and reports
E.	Construction Drawings
F.	Shock/Vibration Reports
G.	Diagrammatic Drawings
H.	Arrangement Drawings
I.	Propeller Data
J.	Structures drawings
K.	Compartment access Drawings
L.	Interface Control Drawings
M.	Calculations and Analyses
N.	Noise Reports
O.	Maintenance manuals
P.	Quarterly Weight Reports
Q.	System Safety Program Plans
R.	EMI Plan and Report
S.	Configuration Management Plan
T.	Inspection Plans
U.	System Descriptions

Table II Typical CDRL List (Tibbits, 1988)

Use of CAD and CAM. The use of CAD and CAM in U.S. Naval design and construction has been limited but is dramatically increasing. CAD was in limited use as a drafting aid on the FFG-7, DD-963 and CG-47 classes. The DDG-51 was bid as an all CAD design, however the technology and training was not in place to make it a reality. The final DDG-51 design was less than 20 percent CAD; however models continue to be developed and the flight upgrade designs are increasingly digitized. The new LPD-17 maybe the first true all CAD surface ship design for the U.S. Navy.

Personnel Training impacts. Designers are generally not trained in production methods. Formal time spent in a shipyard production area is not required. (Bruce, 1988) This is particularly true of the subcontracted designers who work for shipyard-hired design firms.

#### Japan

Detail design can begin under the Japanese system prior to a contract award. (Summers, 1993) This is a contributor to the cost savings perceived in the Aegis destroyer comparison.

The total time for detail design is about three years. For the Kongo it actually started 21 months before contract award. Sixty personnel from Maritime Maritech assisted MHI in the design. MHI has used between 200 and 500 designers on the DD 173 project. (Martin, 1990)

Use of CAD and CAM. The Japanese are using CAD for a fraction (50 percent to 60 percent) of the design of DDG-2313 because the effort is too expensive and the geometry is too complex. (Martin, 1990)

Personnel Training Impacts, Designers are required to spend time in production area as a part of their formal training. (Bruce, 1988) It is of particular interest that in some cases the designers are also trained as installers. After developing the design details, the technician moves from the drawing room to the assembly building or ways, where he performs the installation of his design. (Summers, 1993)

#### Italy

Phase 5 of the Italian Navy process encompasses all of the design and construction activities, including final operational evaluation and vessel acceptance (Craig, 1993)

#### Canada

Called the Reject Implementation Phase in the DPMS. It is similar to the U.S. process, in that the shipyard that wins the construction contract develops the detailed design with the assistance of subcontracted design firms.

#### NATO

Detail Design is part of the Design and Development phase leading up to construction.

#### U.K

Requires 3-6 years for combined detailed design and construction. Detail design is undertaken by the shipyard that is awarded the contract.

#### Comparison

In most countries the winning shipyard performs the detailed design. It appears, however, that the degree of control and oversight resulting in extensive documentation reviews, is much greater in the U.S. than elsewhere. It is also apparent that training designers in production methods and using standard design details, as is done in Japan, can help reduce design costs.

Estimated Cost. Some design cost estimates are provided in the Table III for comparison

Country	ship	Design man-hours
U.S.	DDG-51	6,000,000
Japan	DD-173	1,200,000
U.S.	DD-963	5,000,000
U.S.	CG-47	3,000,000

Table III Design Cost Comparison (Martin, 1990)

Several points are significant in reviewing this table. The CG-47 design utilized the exact hullform and main machinery of the DD-963, but had major system and superstructure changes. The result was a reduction in total detail design required. The DD-173 design closely follows the DDG-51 design, including hullform, systems and superstructure, allowing the Japanese to essentially copy the U.S. design in many cases. The DDG-51 design incorporated a number of features never before designed into Navy ships, and was geometrically and volumetrically constrained by cost, resulting in an extremely complex design with numerous interference issues.

## CONSTRUCTION

Limited quantified data was available for countries other than Japan and the U.S. on actual construction programs. However, the current major construction programs of destroyer or frigate type ships that could be used for a more detailed comparison are included.

### U.S.

It takes at least 3 years to build a major Naval vessel in the U.S. (Tibbits, 1993)

**Subcontracting.** Subcontracting of specific parts of the design is very limited in the U.S. In fact, it is primarily restricted to component vendors who provide system components that cannot be efficiently manufactured within the shipyard.

**Training and Skill Level of Personnel** In most of the shipyards that build major Naval vessels, the production workers are unionized. Cross training has been virtually non-existent however recent labor agreements are changing that. This contributes to some degree to the greater number of man-hours required to

build a ship in the U.S., as it takes several personnel to perform a single task or complete a work unit.

**Current Building Program.** The DDG-51 Arleigh Burke Class Aegis destroyers comprise the primary Naval construction program currently underway in the U.S. The two shipbuilders are Bath Iron Works Corporation and Ingalls Shipbuilding

### Japan

In Japan it also takes about three years to construct a major naval combatant such as the Kongo. (Janes, 1992-93)

**Subcontracting.** KHI-Kobe subcontract activities include scaffold erection, tack weld assembly, finish welding, piping and sheet metal outfitting, painting, accommodations carpentry and joinery, and insulation work. (Bunch, 1987)

**Training and Skill Level of Personnel** The Japanese cross train and utilize all yard personnel. (Martin, 1990) It has been noted that flexible, or cross trained, workers were a major factor in the lower man-hours to build the Kongo. (Sims, 1991)

**Current Building Program** The Japanese have two surface combatant building programs. The most expensive, and most visible, is their version of the Aegis destroyer, the Kongo class. One has been commissioned and three more are under construction

The second program is the Takao Class destroyer, which is an enlarged version of the Asagiri class, of which eight ships were built in the late 1980's. This ship does not incorporate significant stealth or Aegis technology.

### Italy

The major Italian program is the 5400 ton D-560" Animoso class, of which two have been built and two more are planned. (Janes, 1992-93)

### Germany

The Germans are currently in the beginning of a program to build four Type 123 MEKO frigates, displacing about 4490 tons. (Janes, 1992-93)

### Canada

The Canadians are well into the construction of 12 Halifax class 5235 ton frigates. (Janes, 1992-93)

### U.K

The Royal Navy is working on the planned acquisition of as many as 23 Duke Class Type 23 frigates, displacing 4200 tons. (Janes, 1992-93)

country	Ship Type	Approximate <b>Tonnage (Full load)</b>	Keel to Commissioning	Man-hours to Completion
U.S	DDG-51	8315 (Janes 1992)	30 mos (Janes, 1992-93)	-5,000,000 mhrs
U.S.	FFG-7	3500 (Janes, 1992)	30 mos (Sanes, 1992-93)	2500,000 mhrs (Martin, 1990)
Japan	13D-173	9485 (Janes, 1992)	34 mos (Janes, 1992-93)	2,036,400 mhrs (Summers, 1993)
Japan	13D-158	4500 (Janes, 1992)	29 mos (Jams, 1992-93)	1,000,000 mhrs (Martin, 1990)
Italy	D-560	5400 (Janes, 1992)	42 mos (Janes, 1992-93)	
<b>Germany</b>	F-215	4490 (Janes, 1992)	38 mos (Janes, 1992-93)	
Canada	FFH-330	-5235 (Janes, 1992)	51 mos (Janes, 1992-93)	2,100,000 mhrs (Martin, 1990)
Canada	13DG-280	5100 (Janes, 1992)	42 mos (Janes, 1992-93)	2,300,000 mhrs (Martin, 1990)
UK	F-230	4200 (Janes, 1992)	54 mos (Janes, 1992-93)	

Table IV Statistics Comparison

#### Comparison

Constriction Time. The available documentation indicates that the overall time for construction is about the same in Japan, as it is in the U.S. for a similar combatant vessel. (Wines, 1992-93)

Comparison of Acquisition Statistics Table iv firm shows a comparison of estimates found in the literature of costs, man-hours to completion and time from keel laying to delivery.

#### CONCLUSIONS AND RECOMMENDATIONS

The U.S. Naval acquisition, design and construction process has been closely modeled by many other nations, and NATO. It follows an inherently logical path, and has checks and balances built into it. However, there are things that occur in other countries that, should the U.S. emulate their process, may result in overall cost reductions for naval ships. Based on a qualitative "analysis of foreign policies and practices, the following recommendations have been compiled from the Phase by Phase comparisons.

- . Review the early stage process and look for duplications of effort or unnecessary reviews. Develop a defense budgeting system that is longer term, and dedicate a budget for design and construction that suits a predetermined fleet size and make-up. However, flexibility must be retained in order to counter changes in the thlmat.

- . Use a portion of R&D funding to target specific ship and system designs, rather than developing a ship design and looking for R&D products that could be incorporated into it, or developing products and trying

to fit them into a ship. The Japanese are doing it and it saves money in the later stages of design.

- . Establish design-to-cost maximums at the feasibility or concept design stage. Later design phases are then allowed to reduce, but never increase, cost.

- . Consider the use of a selected civilian design or firms to review the Navy design at the feasibility study level and validate the design to cost and design to requirement features of the ship.

- . Develop build strategies during preliminary design. This will bring producibility into play very early in the design cycle, before it becomes cost prohibitive to make producibility driven changes.

- 1 Incorporate life cycle cost decisions into the preliminary design stage. This will dictate commonality, help prevent "gold plating" and have the *eventual* effect of developing a fleet that is cheaper and easier to maintain and operate

- . Change the contract design practices and be consistent. Either use contract drawings that are developed with build strategy, producibility and life cycle costs incorporated, or give the shipbuilder guidance drawings. Coordinate the development and integration of specifications through a *central* function.

- . If competition must be used, then perform pre-bid qualifications at the preliminary design stage so that a build strategy can be incorporated into the contract drawings that is suitable for the qualified yards. Release the RFP only *to the* prequalified shipyards. This will more closely resemble the system that the Japanese are successfully using.

- . Something that was not noted in the Phase comparisons, but came to light in the literature, is that the time frame for a ship development from concept to

service is generally in excess of ten years. However, the longevity of both the military and civilian personnel who participate in the design development is only about three to four years before moving on to another command, organization or project. Assignment of long-term program managers may add consistency to decisions and have a positive effect on the overall cost of project.

- Encourage shipyards to train designers in production efficient design methods and use standard details.

- 1 Provide the means to establish a greater degree of cross training in the production workforce.

- Reduce the level of in-process change that is input to a design. Frozen designs are less expensive than fluid designs.

- 1 In order to establish a meaningful benchmark cost and schedule data should be requested on each of the cited ongoing construction programs and normalized to account for process and financing differences.

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